15. Stock Assessment of Aleutian Islands Atka Mackerel

Sandra Lowe, James Ianelli, Harold Zenger, Kerim Aydin, and Robert Lauth

Executive Summary

Summary of Major Changes

Relative to the November 2004 SAFE report, the following substantive changes have been made in the assessment of Atka mackerel.

Changes in the Input Data

1) Catch data were updated.
2) The 2004 fishery age composition data were included.
3) The 2004 Aleutian Islands survey age composition data were included.

Changes in the Assessment Methodology

There were no changes in the assessment model methodology.

Changes in Assessment Results

1) The mean recruitment (1978-2004) from the stochastic projections is 496 thousand recruits (down about 1% from last year's mean estimate for 1978-2003), which gives an estimated $B_{40\%}$ level of 95,900 mt and an estimated $B_{35\%}$ level of 83,900 mt, down about 3% from last year's estimates of $B_{40\%}$ and $B_{35\%}$.
2) The projected female spawning biomass for 2006 under an $F_{40\%}$ harvest strategy is estimated at 155,800 mt, down about 3% from last year's estimate for 2005; BSAI Atka mackerel are in Tier 3a.
3) The projected age 3+ biomass at the beginning of 2006 is estimated at 446,200 mt, down about 8% from last year's estimate for 2005.
4) The addition of the 2004 fishery and survey age compositions greatly impacted the estimated magnitude of the 1999, 2000, and 2001 year classes. The 2004 fishery selectivity pattern has shifted to reflect greater numbers of younger ages in the catch. The shift in fishery selectivity towards younger ages is reflected in decreases in the estimated $F_{40\%}$ and $F_{35\%}$ fishing mortality rates relative to last year (down about 16%).
5) The projected 2006 yield at $F_{40\%}$= 0.436 is 110,200 mt, down about 11% from last year's estimate for 2005.
6) The projected 2006 overfishing level at $F_{35\%}$ (F = 0.533) is 130,000 mt, down about 11% from last year's estimate for 2005.

Responses to comments by the Scientific and Statistical Committee (SSC)

<u>Comments Specific to the Atka Mackerel Assessment</u>

From the December 2004 SSC minutes: "*The SSC requests that the assessment authors provide support for the assumptions that there is no sexual dimorphism in the schedules for length-at-age and weight-at-length*." The basis for the assumption that there is no sexual dimorphism in the schedules for length-at-age and weight-at-length has been added to the "Length and Weight at Age" section. There have been no indications in the data to suggest differential growth for males and females.

<u>SSC Comments on Assessments in General</u>

From the December 2004 SSC minutes: "*In its review of the SAFE chapter, the SSC noted that there is variation in the information presented. Several years ago, the SSC developed a list of items that should be included in the document. The SSC requests that stock assessment authors exert more effort to address each item contained in the list.*" The authors made a concerted effort to follow the SAFE Guidelines.

15.1 Introduction

Distribution: Atka mackerel (*Pleurogrammus monopterygius*) are distributed along the continental shelf in areas across the North Pacific Ocean and Bering Sea from Asia to North America. On the Asian side they extend from the Kuril Islands to Provideniya Bay (Rutenberg 1962). Moving eastward, they are distributed throughout the Komandorskiye and Aleutian Islands, north to the Pribilof Islands in the eastern Bering Sea, and eastward through the Gulf of Alaska to southeast Alaska. Their center of abundance in Alaska, according to The Alaska Fisheries Science Center (AFSC) resource assessment surveys is the Aleutian Islands, particularly from Buldir Island to Seguam Pass.

Early life history: Until recently, very little has been documented of the early life history of Atka mackerel prior to their appearance in trawl surveys and the fishery at about age 2-3 years. Eggs develop on rocky substrate at depth. Gorbunova (1962) reported that the incubation time for eggs was from 40-45 days, but was not specific about the temperature at which eggs were incubated. Researchers from the Alaska Sea Life Center (ASLC) and University of Alaska Fairbanks (UAF) conducted laboratory experiments to determine the effect of water temperature on incubation rates of Atka mackerel eggs, and found that they ranged from 40 days at 10°C to 105 days at 4°C days (Jared Guthridge ASLC and Nicola Hillgruber UAF, *pers. comm*.). Atka mackerel larvae are found primarily in the neuston from fall through spring and reach maximum abundance in late October (Kendall and Dunn 1985). The mean length of larvae increases from 10.3 mm in the fall to 17.6 mm in the spring (Kendall and Dunn 1985). Larvae can be carried great distances to offshore waters (Gorbunova 1962).

Reproductive ecology: Atka mackerel are sexually dichromatic (Medveditsyna 1962, Rutenberg 1962) and sexually dimorphic (Zolotov 1981). They have a polygamous mating system and are obligate demersal spawners with male parental care. Molecular genetics is being used to study the mating system of Atka mackerel in more detail and early indications are that it is complex and most likely involves alternative reproductive strategies resulting in multiple parentage in a single egg clutch (Mike Canino AFSC, *pers. comm*). Spawning and nesting occur has been observed as shallow as 10 m (Gorbunova 1962) and as deep as 143 m (Lauth et al. *in review*). Possible factors limiting the upper and lower depth limit of Atka mackerel spawning and nesting include kelp, green sea urchins, wave surge, water clarity, light penetration, and temperature (Lauth et al. *in review*, Gorbunova 1962, Zolotov 1993). Spawning begins in June and lasts through October (Gorbunova 1962, Zolotov 1993, McDermott and Lowe 1997, Dan Cooper AFSC, *pers. comm.*). Adhesive eggs are laid on rocky substrates in areas with moderate or strong current in water temperatures ranging from 3.9°C to 10.5°C (Gorbunova 1962, Lauth et al. *in review*). Males exhibiting nesting colors and behaviors begin aggregating at nesting sites in June. In Alaska, nesting sites were observed in the continental shelf regions from Stalemate Bank in the Aleutian archipelago to Unga Island in the Gulf of Alaska. The high abundance of larvae observed offshore of Kodiak Island in the 1970's suggests that nesting grounds have historically extended even further to the east. Males probably remain aggregated at nesting sites into November or December because spawning occurs through October (McDermortt and Lowe 1997) and eggs require a minimum of 40 days to incubate (Gorbunova 1962).

Prey and predators: Adult Atka mackerel in the Aleutians consume a variety of prey, but principally calanoid copepods and euphausiids (Yang 1999), and are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod and arrowtooth flounder, Livingston et al. unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002), and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer et al. 1999).

Nichol and Somerton (2002) examined the diurnal vertical migrations of Atka mackerel using archival tags, and related these movements to light intensity and current velocity. Atka mackerel displayed strong diel behavior, with vertical movements away from the bottom occurring almost exclusively during daylight hours, presumably for feeding, and little to no movement at night (where they were closely associated with the bottom).

Stock structure and management units: A morphological and meristic study suggests there may be separate populations in the Gulf of Alaska and the Aleutian Islands (Levada 1979). This study was based on comparisons of samples collected off Kodiak Island in the central Gulf, and the Rat Islands in the Aleutians. Lee (1985) also conducted a morphological study of Atka mackerel from the Bering Sea, Aleutian Islands and Gulf of Alaska. The data showed some differences (although not consistent by area for each characteristic analyzed), suggesting a certain degree of reproductive isolation. Results from an allozyme genetics study comparing Atka mackerel samples from the western Gulf of Alaska with samples from the eastern, central, and western Aleutian Islands showed no evidence of discrete stocks (Lowe et al. 1998). However, more recent analyses using molecular genetics to evaluate genetic structuring of Atka mackerel have found evidence of weak stock structure (Canino et al. *in review*). A preliminary survey of genetic variation in Atka mackerel using microsatellite DNA markers provided evidence of population structuring over modest geographic scales (400-1150 km). These findings contrast with results from the earlier study using allozymes (Lowe et al. 1998), which showed no evidence for genetic differentiation in Atka mackerel over the same geographic range. Results are concordant with earlier studies indicating potential stock differentiation within the Aleutian Islands based upon morphometric characters. The analyses clearly indicate some degree of genetic stock differentiation, and thus self-recruitment in the Aleutian Islands at more localized scales than are currently realized. Analyses are currently underway to evaluate samples recently collected from the Gulf of Alaska and Japan.

The question remains as to whether the Aleutian Island (AI) and Gulf of Alaska (GOA) populations of Atka mackerel should be managed as a unit stock or separate populations. There are significant differences in population size, distribution, recruitment patterns, and resilience to fishing that suggest otherwise. Bottom trawl surveys and fishery data suggest that the Atka mackerel population in the GOA is smaller and much more patchily distributed than that in the AI, and composed almost entirely of fish >30 cm in length. There are also more areas of moderate Atka mackerel density in the AI than in the GOA. The lack of small fish in the GOA suggests that Atka mackerel recruit to that region differently than in the AI. Nesting sites have been located in the Gulf of Alaska as far east as the Shumagin Islands (Lauth et al. *in review*) and historical ichthyoplankton data from the 70's around Kodiak Island definitely indicate there was a spawning and nesting population even further to the east (Kendall and Dunn 1985), but the source of these spawning populations is unknown. They may be migrant fish from strong year classes in the Aleutian Islands or a self-perpetuating population in the Gulf, or some combination of the two. The idea that the western GOA is the eastern extent of their geographic range might also explain the greater sensitivity to fishing depletion in the GOA as reflected by the history of the GOA fishery since the early 1970s. Catches of Atka mackerel from the GOA peaked in 1975 at about 27,000 mt. Recruitment to the AI population was low from 1980-1985, and catches in the GOA declined to 0 in 1986. Only after a series of large year classes recruited to the AI region in the late 1980s, did the population and fishery reestablish in the GOA beginning in the early 1990s. After passage of these year classes through the population, the GOA population, as sampled in the 1996 and 1999 GOA bottom trawl surveys, has declined and is very patchy in its distribution. Most recently, the strong 1998 and 1999 year classes documented in the Aleutian Islands showed up in the Gulf of Alaska. These differences in population resilience, size, distribution, and recruitment argue for separate assessments and management of the GOA and AI stocks while we await results from microsatellite DNA studies.

15.2 Fishery

15.2.1 Catch history

Annual catches of Atka mackerel in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions increased during the 1970s reaching an initial peak of over 24,000 mt in 1978 (see BSAI SAFE Table 3). Atka mackerel became a reported species group in the BSAI Fishery Management Plan in 1978. Catches (including discards and community development quota [CDQ] catches) by region and corresponding Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council (Council) from 1978 to the present are given in Table 15.1. Table 15.2 documents annual research catches (1977 - 2004) from NMFS trawl surveys.

From 1970-1979, Atka mackerel were landed off Alaska exclusively by the distant water fleets of the U.S.S.R., Japan and the Republic of Korea. U.S. joint venture fisheries began in 1980 and dominated the landings of Atka mackerel from 1982 through 1988. The last joint venture allocation of Atka mackerel off Alaska was in 1989, and since 1990, all Atka mackerel landings have been made by U.S. fishermen. Total landings declined from 1980-1983 primarily due to changes in target species and allocations to various nations rather than changes in stock abundance. Catches increased quickly thereafter, and from 1985-1987 Atka mackerel catches averaged 34,000 mt annually, dropping to a low of 18,000 mt in 1989. Beginning in 1992, TACs increased steadily in response to evidence of a large exploitable biomass, particularly in the central and western Aleutian Islands.

15.2.2 Description of the Directed Fishery

The patterns of the Atka mackerel fishery generally reflect the behavior of the species: (1) the fishery is highly localized and usually occurs in the same few locations each year; (2) the schooling semi-pelagic nature of the species makes it particularly susceptible to trawl gear fished on the bottom; and (3) trawling occurs almost exclusively at depths less than 200 m. In the early 1970s, most Atka mackerel catches were made in the western Aleutian Islands (west of 180°W longitude). In the late 1970s and through the 1980s, fishing effort moved eastward, with the majority of landings occurring near Seguam and Amlia Islands. In 1984 and 1985 the majority of landings came from a single 1/2° latitude by 1° longitude block bounded by 52°30'N, 53°N, 172°W, and 173°W in Seguam Pass (73% in 1984, 52% in 1985). Areas fished by the Atka mackerel fishery from 1977 to 1992 are displayed in Fritz (1993). Areas of 2005 fishery operations are shown in Figure 15.1.

15.2.3 Management History

Prior to 1992, ABCs were allocated to the entire Aleutian management district with no additional spatial management. However, because of increases in the ABC beginning in 1992, the Council recognized the need to disperse fishing effort throughout the range of the stock to minimize the likelihood of localized depletions. In 1993, an initial Atka mackerel TAC of 32,000 mt was caught by 11 March, almost entirely south of Seguam Island. This initial TAC release represented the amount of Atka mackerel that the Council thought could be appropriately harvested in the eastern portion of the Aleutian Islands subarea (based on the assessment for the 1993 fishery; Lowe 1992). In mid-1993, however, Amendment 28 to the Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan became effective, dividing the Aleutian subarea into three districts at 177°W and 177°E for the purposes of spatially apportioning TACs (Figure 15.1). On 11 August 1993, an additional 32,000 mt of Atka mackerel TAC was released to the Central (27,000 mt) and Western (5,000 mt) districts. Since 1994, the BSAI Atka mackerel TAC has been allocated to the three regions based on the average distribution of biomass estimated from the Aleutian Islands bottom trawl surveys.

In June 1998, the Council passed a fishery regulatory amendment that proposed a four-year timetable to temporally and spatially disperse and reduce the level of Atka mackerel fishing within Steller sea lion critical habitat (CH) in the BSAI Islands. Temporal dispersion was accomplished by dividing the BSAI Atka mackerel TAC into two equal seasonal allowances, an A-season beginning January 1 and ending April 15, and a B-season from September 1 to November 1. Spatial dispersion was accomplished through a planned 4-year reduction in the maximum percentage of each seasonal allowance that could be caught within CH in the Central and Western Aleutian Islands. This was in addition to bans on trawling within 10 nm of all sea lion rookeries in the Aleutian district and within 20 nm of the rookeries on Seguam and Agligadak Islands (in area 541), which were instituted in 1992. The goal of spatial dispersion was to reduce the proportion of each seasonal allowance caught within CH to no more than 40% by the year 2002. No CH allowance was established in the Eastern subarea because of the year-round 20 nm trawl exclusion zone around the sea lion rookeries on Seguam and Agligadak Islands that minimized effort within CH. The regulations implementing this four-year phased-in change to Atka mackerel fishery management became effective on 22 January 1999 and lasted only 3 years (through 2001). In 2002, new regulations affecting management of the Atka mackerel, pollock, and Pacific cod fisheries went into effect. Furthermore, all trawling was prohibited in CH from 8 August 2000 through 30 November 2000 by the Western District of the Federal Court because of violations of the Endangered Species Act (ESA).

As part of the plan to respond to the Court and comply with the ESA, NMFS and the NPFMC formulated new regulations for the management of Steller sea lion and groundfish fishery interactions that went into effect in 2002. The objectives of temporal and spatial fishery dispersion, cornerstones of the 1999 regulations, were retained. Season dates and allocations remained the same (A season: 50% of annual TAC from 20 January to 15 April; B season: 50% from 1 September to 1 November). However, the maximum seasonal catch percentage from CH was raised from the goal of 40% in the 1999 regulations to 60%. To compensate, effort within CH in the Central (542) and Western (543) Aleutian fisheries was limited by allowing access to each subarea to half the fleet at a time. Vessels fishing for Atka mackerel are randomly assigned to one of two teams, which start fishing in either area 542 or 543. Vessels may not switch areas until the other team has caught the CH allocation assigned to that area. In the 2002 regulations, trawling for Atka mackerel was prohibited within 10 nm of all rookeries in areas 542 and 543; this was extended to 15 nm around Buldir Island and 3 nm around all major sea lion haulouts. Steller sea lion CH east of 178°W in the Aleutian district, including all CH in subarea 541 and a 1° longitude-wide portion of subarea 542, is closed to directed Atka mackerel fishing.

15.2.4 Bycatch and Discards

Atka mackerel are not commonly caught as bycatch in other directed Aleutian Islands fisheries. The largest amounts of discards of Atka mackerel, which are likely under-size fish, occur in the directed Atka mackerel trawl fishery. Atka mackerel are also caught as bycatch in the trawl Pacific cod and rockfish fisheries. Northern and light dusky rockfish are caught in the Aleutian Islands Atka mackerel fishery. While the 2003 and 2004 discards of northern rockfish as a total of the Atka mackerel catch has remained at about 7-8%, the actual amount of northern discards accounts for a large portion of the AI northern TAC. The 2003 fishery discarded 4,227 mt of northern rockfish, about 72% of the 2003 AI northern TAC. The 2004 Atka mackerel fishery discarded 3,697 mt of northern rockfish which accounted for 74% of the northern TAC.

Discard data have been available for the groundfish fishery since 1990. Discards of Atka mackerel for 1990-1999 have been presented in previous assessments (Lowe et al. 2003). Aleutian Islands discard data from 2000 to the present are given below:

Year	Fishery	Discarded (mt)	Retained (mt)	Total (mt)	Discard Rate (%)
2000	Atka mackerel	2,388	43,977	46,365	5.1
	All others	201	272	473	
	All	2,589	44,249	46,838	
2001	Atka mackerel	3,832	55,744	59,567	6.4
	All others	551	1,217	1,768	
	All	4,384	56,961	61,344	
2002	Atka mackerel	7,125	36,112	43,237	16.5
	All others	239	1,205	1,443	
	All	7,364	37,317	44,680	
2003	Atka mackerel	9,199	41,971	51,170	18.0
	All others	709	1,076	1,785	
	All	9,908	43,046	52,955	
2004	Atka mackerel	6,703	45,814	52,517	12.8
	All others	453	433	885	
	All	7,155	46,247	53,402	

The discards and discard rate of Atka mackerel in the Atka mackerel fishery increased dramatically in 2002. The 2002 fishery caught large numbers of 3 and 4 year olds from the 1998 and 1999 year classes. Small fish from the very large 1999 year class may have contributed to the increased discarding in the 2002 fishery. The discards and discard rate increased again in 2003; the 2003 fishery caught large numbers of 3 and 4 year olds from the 1999 and 2000 year classes, and small fish from the 2000 year class may have contributed to the increased discarding in the 2003 fishery. Most recently, the discard rate has decreased despite the appearance of the above average 2001 year class. It appears that the fishery is retaining larger numbers of 3-year old fish than previous years (see section 15.6.1 Selectivity).

Until 1998, discard rates of Atka mackerel by the target fishery have generally been greatest in the western AI (543) and lowest in the east (541, Lowe et al. 2003). After 1998 and up until 2003, discard rates have been higher in the central AI (542) and have remained lowest in the east (541). However, in 2003, the discard rate in the western AI (543) nearly doubled and exceeded the central area rate. In the 2004 fishery, the discard rates decreased in both the central and western Aleutians (542 & 543), contributing the overall drop in the 2004 discard rate shown above.

Year		Aleutian Islands Subarea 541	542	543
1999	Retained (mt)	14,307	18,036	15,008
	Discarded (mt)	258	2,556	1,197
	Rate	2%	12%	7%
2000	Retained (mt)	13,798	20,720	9,458
	Discarded (mt)	163	1,484	742
	Rate	1%	7%	7%
2001	Retained (mt)	7,632	28,678	19,333
	Discarded (mt)	54	3,102	676
	Rate	1%	10%	3%
2002	Retained (mt)	3,607	17,156	15,348
	Discarded (mt)	213	4,827	2,085
	Rate	6%	22%	12%
2003	Retained (mt)	5,005	22,478	14,488
	Discarded (mt)	354	4,852	3,993
	Rate	7%	18%	22%
2004	Retained (mt)	2,985	26,315	16,514
	Discarded (mt)	244	3,458	3,000
	Rate	8%	12%	15%

15.2.5 Fishery Length Frequencies

From 1977 to 1988, commercial catches were sampled for length and age structures by the NMFS foreign fisheries observer program. There was no JV allocation of Atka mackerel in 1989, when the fishery became fully domestic. Since the domestic observer program was not in full operation until 1990, there was little opportunity to collect age and length data in 1989. Also, the 1980 and 1981 foreign observer samples were small, so these data were supplemented with length samples taken by R.O.K. fisheries personnel from their commercial landings. Data from the foreign fisheries are presented in Lowe and Fritz (1996).

Atka mackerel length distributions from the domestic 2004 and 2005 fisheries by management area and season are shown in Figures 15.2 and 15.3, respectively. Differences in the distributions between the 2004 A- and B-seasons are most notable for the Eastern Aleutians (area 541). The distribution of fish from the 2004 A season showed a mode at 35 cm. This is in contrast to the B season distribution which showed larger fish with a mode at 39 cm, and very few fish less than 35 cm (Figure 15.2). Most of the fish sampled in the Southern Bering Sea (areas 517 & 519) were taken outside of the A and B seasons, therefore all 2004 data are presented. The fish sampled from Bering Sea areas 517 and 519 are larger than fish sampled from the Aleutian Islands, but very similar to the size distributions of fish from the Western Gulf of Alaska (area 610). The modes at about 35-39 cm in the 2004 AI fishery length distributions represent the 1999 year class which dominated the 2004 fishery age composition (Figure 15.4). Only the 2005 A season data are presented and should be considered preliminary (Figure 15.3). The 2005 Central and Western Aleutian A-season fisheries showed similar distributions to the 2004 A and B season distributions with modes at about 35 cm (Figure 15.3).

15.2.6 Steller Sea Lions and Atka mackerel Fishery Interactions

Since 1979, the Atka mackerel fishery has occurred largely within areas designated as Steller sea lion critical habitat in 1993 (20 nm around rookeries and major haulouts). While total removals from critical habitat may be small in relation to estimates of total Atka mackerel biomass in the Aleutian region, fishery harvest rates in localized areas may have been high enough to affect prey availability of Steller sea lions (Section 12.2.2 of Lowe and Fritz 1997). The localized pattern of fishing for Atka mackerel apparently does not affect fishing success from one year to the next since local populations in the Aleutian Islands appear to be replenished by immigration and recruitment. However, this pattern could create temporary reductions in the size and density of localized Atka mackerel populations which could affect Steller sea lion foraging success during the time the fishery is operating and for a period of unknown duration after the fishery is closed. As a consequence, the NPFMC passed regulations in 1998 and 2001 (described above in Section 15.2.3) to disperse fishing effort temporally and spatially as well as reduce effort within Steller sea lion critical habitat.

NMFS is investigating the efficacy of trawl exclusion zones as a fishery-Steller sea lion management tool, and trying to determine the local movement rates of Atka mackerel through tagging studies. In August 1999, the AFSC conducted a pilot survey to explore the variance in survey catches of Atka mackerel and the feasibility of tagging as methods to determine small-scale changes in abundance and distribution. The tagging work was very successful and tagging surveys have been conducted near Seguam Pass (in area 541) in August 2000, 2001 and 2002 (McDermott *et al*. 2005). Results indicate that the 20 nm trawl exclusion zone around the rookeries on Seguam and Agligadak Islands is effective in minimizing disturbance to prey fields within them. The boundary of the 20 nm trawl exclusion zone at Seguam appears to occur at the approximate boundary of two naturally occurring assemblages. The movement rate between the two assemblages is small. Therefore, the results obtained here regarding the efficacy of the trawl exclusion zone may not generally apply to other, smaller zones to the west. The tagging work has been expanded and tagging was conducted inside and outside the 10 nm trawl exclusion zones in Tanaga Pass (in 2002) and near Amchitka Island (in 2003). Movement rates at Tanaga pass appear similar to those at Seguam with the trawl exclusion zones forming natural boundaries to local aggregations. Movement rates at Amchitka appear to be higher relative to Seguam (pers. comm. Elizabeth Logerwell and Susanne McDermott, AFSC). The boundaries at Amchitka bisect Atka mackerel habitat unlike Seguam and Tanaga.

15.3 Data

15.3.1 Fishery Data

Fishery data consist of total catch biomass from 1977 to 2005 (Table 15.1), and the age composition of the catch from 1977-2004 (Table 15.3). Catch-at-age (in numbers) was estimated using the length frequencies described above and age-length keys. The formulas used are described by Kimura (1989). As with the length frequencies, the age data for 1980-1981, 1989, 1992-1993, and 1997 presented problems. The commercial catches in 1980 and 1981 were not sampled for age structures, and there were too few age structures collected in 1989, 1992, 1993, and 1997 to construct age-length keys. Kimura and Ronholt (1988) used the 1980 survey age-length key to estimate the 1980 commercial catch age distribution, and these data were further used to estimate the 1981 commercial catch age distribution with a mixture model (Kimura and Chikuni 1987). However, this method did not provide satisfactory results for the more recent (1989, 1992, 1993 and 1997) catch data and these years were excluded from the analysis.

The most salient features of the estimated catch-at-age (Table 15.3) are the strong 1975, 1977, and 1999 year classes, and the appearance of a large number of 4-year-olds in 1988, 1995, 1996, 1999 and most recently in 2002 and 2003, representing the 1984, 1991, 1992, 1995, and the 1998 and 1999 year classes, respectively. The 1975 year class appeared strong as 3 and 4-year-olds in 1978 and 1979. It is unclear why this year class did not continue to show up strongly after age 4. The 1977 year class appeared strong through 1987, after entering the fishery as 3-year-olds in 1980. The 1988 fishery was basically supported by the 1984 year class which showed up strongly as 4-year-olds. The 1988 year class persisted in large numbers in the 1992-1996 commercial catches, and also dominated the catch in the 1994 survey. The 1996-1998 catch data were dominated by the strong 1992 year class, and the 1999 and 2000 catch data were dominated by the 1995 year class (Table 15.3). The 2002 fishery age data showed the first appearance in the fishery of the strong 1999 year class, and the 2003 fishery data showed the first appearance of large numbers from the 2000 year class. The most recent 2004 fishery age data show the first appearance in the fishery of the 2001 year class, and the 1999 and 2000 year classes continue to show up in large numbers (Table 15.3 and Figure 15.4).

Atka mackerel are a summer-fall spawning fish that do not appear to lay down an otolith annulus in the first year (Anderl et al., 1996). For stock assessment purposes, one year is added to the number of otolith hyaline zones determined by the Alaska Fisheries Science Center Age and Growth Unit. All age data presented in this report have been corrected in this way.

15.3.2 Survey Data

Atka mackerel are a difficult species to survey because: (1) they do not have a swim bladder, making them poor targets for hydroacoustic surveys; (2) they prefer hard, rough and rocky bottom which makes sampling with survey bottom trawl gear difficult; and (3) their schooling behavior and patchy distribution result in survey estimates with large variances. Despite these shortcomings, the U.S.-Japan cooperative trawl surveys conducted in 1980, 1983, 1986, and the 1991, 1994, 1997, 2000, 2002 and 2004 domestic trawl surveys, provide the only direct estimates of population biomass from throughout the Aleutian Islands region. Furthermore, the biomass estimates from the early U.S-Japan cooperative surveys are not directly comparable with the biomass estimates obtained from the U.S. trawl surveys because of differences in the net, fishing power of the vessels, and sampling design (Barbeaux et al. 2003).

Trawl survey biomass estimates of Atka mackerel varied from 197,529 mt in 1980 to 306,780 mt in 1983, and 544,754 mt in 1986 (Table 15.4). However, the high value for 1986 is not directly comparable to previous estimates. During the 1980 survey, no successful sampling occurred in shallow waters (<100 m) around Kiska and Amchitka Islands, and during the 1983 survey very few shallow water stations were successfully trawled. However, during the 1986 survey, several stations were successfully trawled in waters less than 100 m, and some produced extremely large catches of Atka mackerel. In 1986, the biomass estimate from this one depth interval alone totaled 418,000 mt in the Southwest Aleutians (Table 15.4), or 77% of the total biomass of Atka mackerel in the Aleutian Islands. This was a 403,000 mt increase over the 1983 biomass estimate for the same stratum-depth interval. The 1986 biomass estimate is associated with a large coefficient of variation (0.63). Due to differences in area and depth coverage of the surveys, it is not clear how this biomass estimate compares to earlier years.

The most recent biomass estimate from the 2004 Aleutian Islands bottom trawl survey is 886,783 mt, up 15% relative to the 2002 survey estimate (Table 15.5). Previous to this, the 2002 Aleutian Islands bottom trawl survey biomass estimate of 772,798 mt increased 51% relative to the 2000 survey. The breakdown of the Aleutian biomass estimates by area corresponds to the management sub-districts (541-Eastern, 542-Central, and 543-Western). The increase in biomass in the 2004 survey is largely a result of an increase in biomass found in the Western area (372,782 mt). Relative to the 2002 survey, the 2004 biomass estimates are up 46% in the Western area, down 17% in the Central area, and up 28% in the Eastern area (Figure 15.5). The 95% confidence interval about the mean total 2004 Aleutian biomass estimate is **771,645-1,537,033** mt. The coefficient of variation (*CV*) of the 2004 mean Aleutian biomass is 17%, consistent with the *CV* from the 2002 survey, and the lowest since the 1991 survey (Table 15.5).

The distribution of biomass in the Western, Central, and Eastern Aleutians, and the southern Bering Sea shifted between each of the surveys, and most dramatically in area 541 in the 2000 survey (Figure 15.5).

The 2000 Eastern area biomass estimate (900 mt) was the lowest of all surveys, contributing only 0.2% of the total 2000 Aleutian biomass and represented a 98% decline relative to the 1997 survey. The extremely low 2000 biomass estimate for the Eastern area has not been reconciled, but there are several factors that may have had a significant impact on the distribution of Atka mackerel that were discussed in Lowe et al. (2001). We note that the distribution of Atka mackerel in the Eastern area is generally patchier, and up until the 2004 survey, the area-specific variances for the Eastern area have always been high relative to the Central and Western areas. Lowe et al. (2001) suggest that a combination of several factors coupled with the typically patchier distribution of Atka mackerel in area 541 may have impacted the distribution of the fish such that they were not available at the surveyed stations at the time of the 2000 survey. The 2004 survey showed that the Eastern area contributed 28% of the total biomass, which is little change from 25% of the biomass that was detected in the 2002 survey.

In both 1991 and 1994, the Western area contributed approximately half of the total estimated Aleutian biomass, but this proportion dropped each subsequent survey to 33% in 2002. The proportion of biomass in the Western area increased to 42% in the most recent 2004 survey. In 1994, 14% of the Aleutian biomass was found in the Central area compared to 51% in 1997 and up to 65% 2000 survey. The most recent 2004 survey showed the Central area contributing 30% of the Aleutian biomass (Table 15.5).

In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,603 mt). This occurred again in 1997 (95,680 mt), 2002 (59,883 mt), and most recently in the 2004 survey (267,556 mt, Table 15.5). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all four surveys. In addition, large catches of Atka mackerel in the 2004 survey were also encountered north of Unalaska Island, with a particularly large haul in the northwest corner of Unalaska Island (Figure 15.6). The 2004 southern Bering Sea strata biomass estimate of 267,556 mt is the largest biomass encountered in this area in the survey time series. The *CV* of the 2004 southern Bering Sea estimate is 43% much lower than previous years as several hauls contributed to the 2004 estimate.

Areas with large catches of Atka mackerel during the 2000 survey, included Tanaga Pass, south of Amchitka Island, Buldir Island, and Stalemate Bank (Figure 15.6). In the 2002 survey, areas with large catches were located north of Akun Island, Seguam Pass, Tanaga Pass, south of Amchitka Island, Kiska Island, Buldir Island, and Stalemate Bank (Figure 15.6). Areas with large catches of Atka mackerel during the 2004 survey included north of Akun Island and Unalaska Islands, Seguam Pass, Tanaga Pass, Kiska Island, Buldir Island, and Stalemate Bank (Figure 15.6). In the 2002 and 2004 surveys, Atka mackerel were much less patchily distributed relative to previous surveys and were encountered in 55% and 58% of the hauls respectively, which are the highest rates of encounters in the survey time series.

The average bottom temperatures measured in the 2000 survey were the lowest of any of the Aleutian surveys, particularly in depths less than 200 m where 99% of the Atka mackerel are caught in the surveys (pers. comm., Harold Zenger, AFSC, Figure 15.7). The average bottom temperatures measured in the 2002 survey were the second lowest of the Aleutian surveys, but significantly higher than the 2000 survey and very similar to the 1994 survey. The average bottom temperatures measured in the 2004 survey fell right about in the middle of the series for all survey years, excluding the year 2000.

There is greater confidence in Atka mackerel biomass estimates from bottom trawl surveys of the groundfish community of the Aleutian Islands (AI) than the Gulf of Alaska (GOA). First, the coefficients of variation of the mean Atka mackerel biomass estimates have been considerably smaller from the recent AI surveys than the recent GOA surveys: 0.29, 0.28, 0.20, and 0.17 from the 1997, 2000, 2002, and 2004 AI surveys, respectively, compared with 0.99, 0.45, 1.00, 0.35, and 0.50 from the 1996, 1999, 2001, 2003, and 2005 GOA surveys. Second, while patchy in its distribution compared to other groundfish species, Atka mackerel have been much more consistently encountered in the AI than the GOA surveys, appearing in 41%, 33%, 23%, 33%, 55%, and 58% of the hauls in the 1991, 1994, 1997, 2000, 2002, and 2004 AI surveys, compared to 5%, 28%, 13%, 20%, 10%, 44%, and 29% of the hauls in the Shumagin area in the 1990, 1993, 1996, 1999, 2001, 2003, and 2005 GOA surveys, respectively. For these reasons we utilize bottom trawl surveys to assess the relative abundance of Atka mackerel in the Aleutian Islands, but do not consider the highly variable estimates of biomass from the GOA surveys useful for tracking abundance trends.

Survey Length Frequencies

The 2000 and 2002 bottom trawl surveys and the fishery catch data revealed a strong east-west gradient in Atka mackerel size, with the smallest fish in the west and progressively larger fish to the east, (Figure 15.8 in Lowe et al. 2003). The 2004 survey length frequency distributions also showed a strong east-west gradient in Atka mackerel size, but the Western and Central distributions were very similar with modes at 33-34 cm (Figure 15.8), similar to the 2004 fishery data in these areas (Figure 15.2). The 2004 survey length frequency distributions from the Eastern area showed a mode of fish at 37 cm, larger than the Central and Western fish, but significantly smaller compared to the size distribution of fish sampled from the southern Bering Sea with a mode of 43 cm (Figure 15.8).

Survey Age Frequencies

The age compositions from the 2000, 2002, and 2004 Aleutian surveys are shown in Figure 15.9. The 2000 survey age composition shows the strong 1992 and 1995 year classes (8 and 5-year olds, respectively), and a very strong showing of 2-year-olds from the 1998 year class (Figure 15.9). The selectivity of 2 year olds in the survey is thought to be fairly low, and this age group has not shown up in significant proportions in previous surveys (Lowe et al. 2003). The 2002 survey age composition is dominated by the 1999 year class and continues to show large numbers of the 1998 year class (Figure 15.9). The 2004 survey age data is basically comprised of 3, 4, and 5-year olds of the 1999, 2000, and 2001 year classes, and is dominated by 3-year olds of the 2001 year class (Figure 15.9). The mean ages of the 2000, 2002, and 2004 surveys are 5.0, 3.8, and 4.2 years, respectively. The mean age in the 2002 survey of 3.8 years is the youngest mean age of any survey.

Survey Abundance Indices

A partial time series of relative indices from the 1980, 1983, 1986, and 1991 Aleutian Islands surveys had been used in the previous stock synthesis assessments (Lowe et al. 2001). The relative indices of abundance excluded biomass from the 1-100 m depth strata of the Southwest Aleutian Islands region (west of 180°) due to the lack of sampling in this strata in some years. Because the excluded area and depth strata have consistently been found to be locations of high Atka mackerel biomass in later surveys, it was determined that the indices did not provide useful additional information to the model. Analyses to determine the impact of omitting the relative time series in the Stock Assessment Toolbox model showed that results without the relative index are more conservative. The Stock Assessment Toolbox model results corroborated previous assessments which explored the impact of incorporating the early survey index (Lowe 1991). That is, synthesis results showed that including the survey index resulted in higher historical biomass estimates.

15.4 Analytic approach

The 2002 BSAI Atka mackerel stock assessment introduced a new modeling approach implemented through the “Stock Assessment Toolbox“ (an initiative by the NOAA Fisheries Office of Science and Technology) that evaluated favorably with previous assessments (Lowe et al. 2002). This approach used the Assessment Model for Alaska (AMAK)[1] from the Toolbox, which is similar to the stock synthesis application (Methot 1989, 1990; Fournier and Archibald 1982) used for Aleutian Islands Atka mackerel from 1991 – 2001, but allows for increased flexibility in specifying models with uncertainty in changes in fishery selectivity and other parameters such as natural mortality and survey catchability (Lowe et al. 2002). This approach (AMAK) has also been adopted for the Aleutian Islands (Barbeaux et al. 2004) and Bogoslof pollock stock assessments (J. Ianelli, AFSC, pers. comm).

The Assessment Model for Alaska is developed using ADModel Builder language (ADMB, Fournier 1998; Ianelli and Fournier 1998). The ADMB is a C++ software language extension and automatic differentiation library. It allows for estimation of large numbers of parameters in non-linear models using automatic differentiation software developed into C++ libraries (Fournier 1998). The optimizer in ADMB is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1×10^{-7}). A feature of ADMB is that it includes post-convergence routines to calculate standard errors (or likelihood profiles) for quantities of interest.

15.4.1 Model structure

The AMAK models catch-at-age with the standard Baravov catch equation. The population dynamics follows numbers-at-age over the period of catch history (here 1977-2004) with natural and age-specific fishing mortality occurring throughout the 15-age-groups that are modeled (ages 1-15+). Age 1 recruitment in each year is estimated as deviations from a mean value expected from an underlying stock-recruitment curve. Deviations between the observations and the expected values are quantified with a specified error model and cast in terms of a penalized log-likelihood. The overall log-likelihood (*L*) is the weighted sum of the calculated log-likelihoods for each data component and model penalties. The component weights are inversely proportional to the specified (or in some cases, estimated) variances Appendix Tables A-1 – A-3 provide a description of the variables used, and the basic equations describing the population dynamics of Atka mackerel as they relate to the available data. The quasi[2] likelihood components and the distribution assumption of the error structure are given below:

Likelihood Component	Distribution Assumption
Catch biomass	Lognormal
Catch age composition	Multinomial
Survey catch biomass	Lognormal
Survey catch age composition	Multinomial
Recruitment deviations	Lognormal
Stock recruitment curve	Lognormal
Selectivity smoothness (in age-coefficients, survey and fishery)	Lognormal
Selectivity change over time (fishery only)	Lognormal
Priors (where applicable)	Lognormal

[1] AMAK. 2005. A statistical catch at age model for Alaska, version 1.1. NOAA Fisheries Toolbox. NEFSC, Woods Hole, MA. Available at http://nft.nefsc.noaa.gov/beta

[2] Quasi likelihood is used here because model penalties (not strictly relating to data) are included.

Parameters estimated independently

Natural Mortality

Natural mortality (M) is a difficult parameter to estimate reliably. One approach we took was to use the regression model of Hoenig (1983) which relates total mortality as a function of maximum age. His equation is:

$$\ln(Z) = 1.46 - 1.01(\ln(Tmax)).$$

Where Z is total instantaneous mortality (the sum of natural and fishing mortality, $Z=M+F$), and $Tmax$ is the maximum age. The instantaneous total mortality rate can be considered an upper bound for the natural mortality rate if the fishing mortality rate is minimal. The catch-at-age data showed a 14-year-old fish in the 1990 fishery, and a 15-year-old in the 1994 fishery. Assuming a maximum age of 14 years and Hoenig's regression equation, Z was estimated to be 0.30 (Lowe 1992). Since fishing mortality was relatively low in 1990, natural mortality has been reasonably approximated by a value of 0.30 in past assessments.

An analysis was undertaken to explore alternative methods to estimate natural mortality for Atka mackerel (Lowe and Fritz, 1997). Several methods were employed based on correlations of M with life history parameters including growth parameters (Alverson and Carney 1975, Pauly 1980, Charnov 1993), longevity (Hoenig 1983), and reproductive potential (Roff 1986, Rikhter and Efanov 1976). Atka mackerel appear to be segregated by size along the Aleutian chain. Thus, natural mortality estimates based on growth parameters would be sensitive to any sampling biases that could result in under- or over-estimation of the von Bertalanffy growth parameters. Fishery data collections are more likely to be biased as the fishery can be more size selective and concentrates harvests in specific areas as opposed to the surveys. Natural mortality estimates derived from fishery data ranged from 0.05 to 1.13 with a mean of 0.53. Natural mortality estimates, excluding those based on fishery data, ranged from 0.12 to 0.74 with a mean value of 0.34. The current assumed value of 0.3 is consistent with these values. Also, a value of 0.3 is consistent with values of M derived by the methods of Hoenig (1983) and Rikhter and Efanov (1976) which do not rely on growth parameters (Lowe and Fritz, 1997).

The 2003 assessment explored the use of priors on M, resulting in drastically inflated biomass levels (Figure 15.11 in Lowe et al. 2003). Independent studies are being conducted outside the assessment which may provide further information to configure appropriate prior distributions for M. In the current assessment, a natural mortality value of 0.3 was used for all models.

Length and Weight at Age

Atka mackerel exhibit large annual and geographic variability in length at age. Because survey data provide the most uniform sampling of the Aleutian Islands region, data from these surveys were used to evaluate variability in growth (Kimura and Ronholt 1988, Lowe et al. 1998). Kimura and Ronholt (1988) conducted an analysis of variance on length-at-age data from the 1980, 1983, and 1986 U.S.-Japan surveys, and the U.S.-U.S.S.R. surveys in 1982 and 1985, stratified by six areas. Results showed that length at age did not differ significantly by sex, and was smallest in the west and largest in the east. More recent analyses by Lowe et al. (1998) corroborated differential growth in three sub-areas of the Aleutian Islands and the Western Gulf of Alaska.

Based on the work of Kimura and Ronholt (1988), and annual examination of length and age data by sex which has found no differences, growth parameters are presented for combined sexes. Parameters of the von Bertalanffy length-age equation and a weight-length equation have been calculated for (1) the combined 1986, 1991, and 1994 survey data for the entire Aleutians region, and for the Eastern (541) and combined Central and Western (542 and 543) subareas, and (2) the combined 1990-96 fishery data for the same areas:

Data source	L_∞(cm)	K	t_0
86, 91& 94 surveys			
Areas combined	41.4	0.439	-0.13
541	42.1	0.652	0.70
542 & 543	40.3	0.425	-0.38
1990-96 fishery			
Areas combined	41.3	0.670	0.79
541	44.1	0.518	0.35
542 & 543	40.7	0.562	0.37

Length-age equation: Length (cm) = $L_\infty\{1-\exp[-K(\text{age}-t_0)]\}$

Both the survey and fishery data show a clear east to west size cline in length at age with the largest fish found in the eastern Aleutians.

The weight-length relationship determined from the same data sets are as follows:

weight (kg) = 9.08E-06 * length (cm) $^{3.0913}$ (86, 91 & 94 surveys; N=1,052)
weight (kg) = 3.72E-05 * length (cm) $^{2.6949}$ (1990-1996 fisheries; N=4,041).

The observed differences in the weight-length relationships from the survey and fishery data, particularly in the exponent of length, probably reflect the differences in the timing of sample collection. The survey data were all collected in summer, the spawning period of Atka mackerel when gonad weight would contribute the most to total weight. The fishery data were collected primarily in winter, when gonad weight would be a smaller percentage of total weight than in summer. The average length-at age and weights-at-age for combined sexes used in the model are given in Table 15.6.

Maturity at Age

Female maturity at length and age were determined for Aleutian Islands Atka mackerel (McDermott and Lowe, 1997). The age at 50% maturity is 3.6 years. Length at 50% maturity differs by area as the length at age differs by Aleutian Islands sub-areas:

	Length at 50% maturity (cm)
Eastern Aleutians (541)	35.91
Central Aleutians (542)	33.55
Western Aleutians (543)	33.64

The maturity schedules are given in Table 15.7. Work is currently underway to re-examine and update the maturity information (pers. comm. Susanne McDermott and Dan Cooper, AFSC).

Parameters estimated conditionally

Deviations between the observations and the expected values are quantified with a specified error structure. Lognormal error is assumed for survey biomass estimates and fishery catch, and a multinomial error structure is assumed for survey and fishery age compositions. These error structures are used to estimate the following parameters conditionally within the model.

Fishing Mortality

Fishing mortality is parameterized to be separable with a year component and an age (selectivity) component in all models. The selectivity relationship is modeled with a smoothed non-parametric relationship that can take on any shape (with penalties controlling the degree of change and curvature specified by the user; Table A-2). Selectivity is conditioned so that the mean value over all ages will be equal to one. To provide regularity in the age component, a moderate penalty was imposed on sharp shifts in selectivity between ages using the sum of squared second differences (log-scale). In addition, the age component parameters are assumed constant for the last 6 age groups (ages 10-15). Asymptotic growth is reached at about age 9 to 10 years. Thus, it seemed reasonable to assume that selectivity of fish older than age 10 would be the same. Selectivity is allowed to vary annually with a low constraint as in the selected Reference model from the 2003 assessment (Lowe et al. 2003).

Survey Catchability

For the bottom trawl survey, catchability-at-age follows a parameterization similar to the fishery selectivity-at-age presented above (except with no allowance for time-varying selectivity). Here we specified that the average selectivity-at-age for the survey is equal to 1 over ages 4-10. This was done to standardize the ages over which catchability most reasonably applies. The 2003 assessment explored the use of a prior on survey catchability (q) through AMACK with mixed results that were difficult to interpret biologically (Lowe et al. 2003). Last year we presented a model (Model 4, Lowe et al. 2004), with a moderate prior on q (mean = 1.0, $\sigma^2 = 0.2^2$) which was accepted and used as the basis for the 2005 ABC and OFL. This year we carry forward the accepted model from last year's assessment (moderate prior on q, mean = 1.0, $\sigma^2 = 0.2^2$) for evaluation.

Recruitment

The Beverton-Holt form of stock recruitment relationship based on Francis (1992) was used (Table A-2). Values for the stock recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (h, Table A-2). The "steepness" parameter is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992). We assumed a steepness value of 0.8 for all model runs presented here, with a 30% *CV*. A value of h = 0.8 implies that at 20% of the unfished spawning stock size, an expected value of 80% of the unfished recruitment level will result. Model runs exploring other values of h and the use of a prior on h were explored in previous assessments (Lowe et al. 2002), but were found to have little or no bearing on the stock assessment results and were not carried forward for further evaluation at the time.

15.5 Model Evaluation

Last year a number of refinements were made to the model configuration (Lowe et al. 2004). These changes were restricted to three key assumptions. The first change was to correct the model to account for the time of year that the survey takes place. Previously, it had simply assumed begin-year biomass was a suitable proxy. Second, we specified a lognormal error distribution for survey data (the convention in most stock assessment models) instead of a normal distribution which had previously been assumed. The third model configuration change was to assume a moderate prior on survey catchability q (μ=1.0, σ^2=0.2^2). Prior to the 2004 assessment, survey catchability had been fixed at 1.0. Model 4 in last year's assessment incorporated the above changes and was the basis for 2005 ABC and OFL recommendations

(Lowe et al. 2004). We again carry forward Model 4 in the current assessment, and a summary of last year's evaluation follows.

The 2004 assessment evaluated several models and found that Model 4 fit the survey index best as indicated by the lowest survey residual mean square error (RMSE) and –ln(survey likelihood), and also fit the survey age composition best (Lowe et al. 2004). Model 4 resulted in reductions (relative to the Baseline Model) in the *CV*s for the estimates of 2004 total biomass and the 1998 year class (at age 1). These reductions in variability about biomass and recruitment translated to reductions (relative to the Baseline Model) in the *CV*s for projected $F_{40\%}$ and $F_{35\%}$ 2004 catches (Table 15.9 in Lowe et al. 2004). Survey catchability for Model 4 was estimated at 1.405 in the 2004 assessment and estimated at 1.429 in the current assessment (Table 15.8). Given that there are inconsistencies between the fishery and survey data sources and large uncertainty about q, a model that reflects some indication that q>1.0 is appropriate and consistent with findings of q>1.0 from several past model explorations with priors on M and q (Lowe et al. 2002 and Lowe et al. 2003).

Model 4 was determined to provide the most biologically reasonable configuration (Lowe et al. 2004). It is important to include 6 months of within-year mortality for computing modeled survey abundance. Also, assuming a lognormal error is most appropriate for survey biomass due to the nature of Atka mackerel and their highly variable survey abundance patterns. Previous studies illustrated the sensitivity to assumptions about q and M and highlighted the need for further independent studies on these quantities. Results from such studies are as yet unavailable. However, it seems prudent to include a model with a moderate prior on q (μ=1.0, σ^2=0.2^2). Note that the assumption that q=1.0 with no uncertainty is also unsatisfactory, especially since preliminary explorations indicate that q is likely greater than 1.0. A value of q somewhat greater than 1.0 could be plausible, considering the patchy distribution and schooling nature of Atka mackerel. Past surveys have shown the impacts of a few extremely large hauls which skew the mean, and are then extrapolated over the entire strata. Therefore, we again carry forward Model 4 as a reasonable representation of BSAI Atka mackerel dynamics which acknowledges some uncertainty about q.

15.6 Model Results

The results discussed below are based on Model 4.

15.6.1 Selectivity

The estimated selectivity at age schedules for the fishery and survey are shown in Figures 15.10-15.12 and given in Table 15.9.

The fishery catches essentially consist of fish 3-12 years old, although a 15-year-old fish was found in the 1994 fishery. The fishery exhibits a dome-shaped selectivity pattern which is particularly strong prior to 1991 during the foreign and joint venture fisheries (Figure 15.10). After 1991, fishery selectivity patterns are fairly similar with gradual transitions, particularly between the ages of 3-9. The 2004 estimate of selectivity at age reflects the large numbers of 5-year old fish from the 1999 year class (Figure 15.10).

For Atka mackerel, the estimated selectivity patterns are particularly important in describing their dynamics. Previous assessments have focused on the transitions between ages and time-varying selectivity (Lowe et al. 2002). As noted above, after 1991 the selectivity patterns are fairly consistent but do reflect annual variability. The estimated selectivity patterns for 2003 and 2004 are shown for comparison (Figure 15.11). The 2003 catch at age data still included large numbers of 7-year olds from the 1995 year class, while the 2004 pattern reflects the large numbers of 4 and 5 year olds (2000 and 1999 year classes) in the 2004 catch. The age at 50% selectivity is estimated at about age 3.5 for both 2003 and

2004 (Figure 15.11). This is the youngest age at 50% selectivity in recent years due to the particularly strong showing of the 1999 year class (Tables 15.3 and 15.9). Fish older than age 9 make up a very small percentage of the population each year (Table 15.10), and the differences in the selectivity assumptions for the older ages are not likely to have a large impact. However, differences in selectivity for ages 3-8 can have a significant impact. It is important to note the maturity-at-age vector which falls between the estimated 2003 and 2004 selectivity patterns (age at 50% maturity is 3.6 years, Figure 15.11). The estimated 2004 selectivity pattern indicates the current fishery is harvesting greater numbers of younger, immature fish. The average selectivity pattern estimated for the years 2000 to 2004 is shown for perspective (Figure 15.11).

Survey catches are mostly comprised of fish 3-9 years old. A 14-year old fish was found in the 1994 survey and a 15-year old fish was found in the 2000 survey. The current configuration estimates a smoothed slightly dome-shaped selectivity pattern (Figure 15.12).

15.6.2 Abundance Trend

The estimated time series of total biomass with approximate upper and lower 95% confidence limits are shown in Figure 15.13 and given in Table 15.11. For comparison, the time series of spawning biomass from the 2004 and 2005 (current) assessments are also plotted (Figure 15.14). The corresponding time series of total numbers at age are given in Table 15.10.

A comparison of the spawning biomass trend from the current and previous assessments (Figure 15.14, Table 15.11) indicates consistent (nearly identical) trends throughout the time series, i.e., biomass increased during the early 80s and again in the late 80s to early 90s. After the estimated peak spawning biomass in 1993, spawning biomass declined for nearly 10 years until 2002, thereafter, spawning biomass began a steep increase which continues to 2005 as estimated in the current assessment. Recent (after 2002) estimated spawning biomass levels are slightly lower in the current assessment due to revised (downward) estimates of the magnitude of the 1998 and 1999 year classes with the addition of the 2004 fishery and survey age compositions. Although the current assessment estimates significantly higher numbers of recruits from the 2001 year class (see Recruitment Trend below), these fish are still too small to contribute significantly to the spawning biomass population. Thus, estimates of recent spawning biomass levels are somewhat moderated relative to last year’s assessment.

15.6.3 Recruitment Trend

The estimated time series of age 1 recruits from the current assessment and the 2004 assessment is shown in Figure 15.15 and given in Table 15.12. The strong 1977 year class is most notable in the current assessment, followed by the 1988, and 1999 year classes. The current estimates of the 1998 and 1999 year classes have decreased in magnitude relative to the 2004 assessment due to the addition of the 2004 survey and fishery age compositions (Figure 15.15). The 1999 year class which was estimated as the largest year class in last year’s assessment, is now estimated to be the third largest year class in the time series, in line with the 1977 and 1988 year classes (approximately 1.1 million recruits). The current assessment estimates above average (greater than 20% of the mean) recruitment from the 1977, 1986, 1988, 1992, 1995, 1998, 1999, 2000, and 2001 year classes (Figure 15.15). The 2004 survey and fishery catches were basically comprised of 3, 4, and 5-year olds of the 1999, 2000 and 2001 year classes, respectively. The 2004 fishery data was still dominated by the 1999 year class (Figure 15.4), while the 2004 survey provided the first indication of a potentially strong 2001 year class which dominated the survey catches (Figure 15.9).

The average estimated recruitment from the time series 1978-2004 is 496 thousand fish and the median is 392 thousand fish (Table 15.12). The entire time series of recruitments (1977-2004) includes the 1976-2003 year classes. The Alaska Fisheries Science Center has recognized that an environmental “regime shift" affecting the long-term productive capacity of the groundfish stocks in the BSAI occurred during the period 1976-1977. Thus, the average recruitment value presented in the assessment is based on year classes spawned after 1976 (1977-2004 year classes). Projections of biomass are based on estimated recruitments from 1978-2004 using a stochastic projection model described below.

15.6.4 Trend in Exploitation

The estimated time series of fishing mortalities on fully selected age groups and the catch-to-biomass (age 3+) ratios are given in Table 15.13 and shown in Figure 15.16

15.6.5 Model Fit

A summary of key results from Model 4 are presented in Table 15.8. The coefficient of variation or *CV* (reflecting uncertainty) about the 2005 biomass estimate is 17% and the *CV*s on the strength of the 1999 and 2001 year classes at age 1 are 30 and 47%, respectively (Table 15.8). Overall estimated recruitment variability for BSAI Atka mackerel is high (0.594). Sample size values were fixed at 100 for the fishery data, and 50 for the bottom trawl survey data. The model estimated an average fishery effective sample size (*N*) of 115 and average survey effective *N* of 48, which compare well with the fixed values. The overall residual mean square error (RMSE) for the survey is estimated at 0.278 (Table 15.8). The RMSE is in line with estimates of sampling-error *CV*s for the survey which range from 15-63% and average 29% over the time series. The sampling-error variances should be considered as minimal estimates. Other sources of uncertainty (e.g., due to spatial variability and environmental conditions) can inflate the uncertainty associated with survey biomass estimates.

Figure 15.17 compares the observed and estimated survey biomass abundance values. Model fits to the survey are greatly improved relative to the 2003 assessment under the old model configuration (see Figure 15.19 in Lowe et al. 2003). However, the model still fits the 1986 survey estimate very poorly. The catch-at-age data do not show another strong year class following the 1977 year class that would allow the model to achieve a better fit to the 1986 survey estimate. This lack of fit is confounded by the large coefficient of variation associated with the 1986 biomass estimate (63%). The large decrease in biomass indicated by the 1994 and 1997 surveys followed by the large increases in biomass from the 2000, 2002, and 2004 surveys appear to be consistent with recruitment patterns. However, we note that the model's predicted survey biomass trend is very conservative relative to the recent (2000, 2002, and 2004) observed bottom trawl survey biomass values (Figure 15.17).

The fits to the survey and fishery age compositions for Model 4 are depicted in Figures 15.18 and 15.19. The model fits the fishery age composition data quite well and the survey age composition data less so. This reflects the fact that the sample sizes for age and length composition data are higher for the fishery than the survey. The exception is the fit to the 2002 survey age composition which is quite good and the best fit in the survey time series (Figure 15.18). These figures also highlight the patterns in changing age compositions over time. Note that the older age groups in the fishery age data are largely absent until around 1985 when the 1977 year class appears. It is also interesting to note that the 2000 survey observed much greater than expected numbers of 2-year old fish (1998 year class) for which the selectivity is estimated to be relatively low (0.15). The observed number of 3 and 4-year olds (1997 and 1996 year classes) in 2000 was much lower than expected even though the estimated selectivity is about 60% for 3 year olds, and 4 year olds are expected to be nearly fully selected (Figure 15.12). It is interesting to note that both the 2004 survey and fishery age compositions observed greater numbers than expected of 3-year olds of the 2001 year class (Figure 15.18 and 15.19).

15.7 Projections and harvest alternatives

15.7.1 Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC (*max* F_{ABC}). The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. The overfishing and maximum allowable ABC fishing mortality rates are given in terms of percentages of unfished female spawning biomass ($F_{SPR\%}$), on fully selected age groups. The associated long-term average female spawning biomass that would be expected under average estimated recruitment from 1978-2004 (496 thousand age 1 recruits) and F equal to $F_{40\%}$ and $F_{35\%}$ are denoted $B_{40\%}$ and $B_{35\%}$, respectively. The Tiers require reference point estimates for biomass level determinations. We present the following reference points for BSAI Atka mackerel for Tier 3 of Amendment 56. For our analyses, we computed the following values from Model 4 results based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 239,700 mt female spawning biomass

$B_{40\%}$ = 95,900 mt female spawning biomass

$B_{35\%}$ = 83,900 mt female spawning biomass

15.7.2 Specification of OFL and Maximum Permissible ABC

The default projection model uses the ending year selectivity vector from the main model, in this case, the year 2005 selectivity vector. Note that the fishery catch-at-age data exists only up through 2004; the 2005 selectivity vector is a smoothed estimate based on the 2004 selectivity pattern. Model results are sensitive to the selectivity assumptions and this is reflected in the reference fishing mortality values. While we believe the current model configuration regarding selectivity assumptions is reasonable, and that it is important to allow some degree of time-varying selectivity to capture the nature of the fishery, for ABC projection purposes we use an average of recent years. To provide for a more robust selectivity pattern for projection purposes, we use an average of the years 2000-2004 (Table 15.9, Figure 15.11). These years reflect a reasonable range of recent selectivity estimates since the implementation of Steller sea lion regulations that affect the Atka mackerel fishery. This change was first discussed and implemented in the 2003 assessment (Lowe et al. 2003). The 2005 ABC projection was based on an average of the years 1999-2003. A comparison of key reference fishing mortality values under the different selectivity assumptions are given below:

	Selectivity Assumption	
Full selection *F*s	2005	Average 2000-2004
F_{2005}	0.131	0.204
$F_{40\%}$	0.262	0.436
$F_{35\%}$	0.316	0.533
$F_{2005}/F_{40\%}$	0.499	0.468

The rates based on the year 2005 selectivity are those presented in the results Table 15.8. Recommendations provided below are based on projections incorporating the average selectivity vector for the years 2000-2004.

For Model 4, the projected year 2006 female spawning biomass (SB_{05}) is estimated to be 155,800 mt under the maximum allowable ABC harvest strategy ($F_{40\%}$). It should be noted that for BSAI Atka mackerel, projected female spawning biomass calculations depend on the harvest strategy because spawning biomass is estimated at peak spawning (August), thus projections incorporate 7 months of the specified fishing mortality rate. The projected 2006 and 2007 female spawning biomass is above the $B_{40\%}$ value of 95,900 mt, placing BSAI Atka mackerel in **Tier 3a**. The maximum permissible ABC and OFL values under Tier 3a are:

Year	Catch	Maximum Permissible ABC	OFL	SSB
2006	63,000	110,200	130,000	155,800
2007		90,000	107,300	112,700

Note that the maximum permissible $F_{ABC} = F_{40\%} = 0.436$ and $F_{OFL}=F_{35\%} = 0.533$; also, catch in 2006 is assumed to be similar to the 2005 TAC.

15.8 ABC Recommendation

Several observations and characterizations of uncertainty in the Atka mackerel assessment have been noted for ABC considerations since 1997.

1) Trawl survey estimates of biomass are highly variable; the 1997 Aleutian trawl survey biomass estimate was about 40% lower than the 1994 survey estimate, while the 2000, 2002, and 2004 survey estimates showed 40, 50, and 15% increases respectively.

2) Under an $F_{40\%}$ harvest strategy, 2006 female spawning biomass is projected to be above $B_{40\%}$ but drop below in 2008 to 2010 (Figure 15.20). However, it should be noted that in recent years the TAC has been set below ABC thus, actual *F*s have been below $F_{40\%}$.

3) The uncertainty about the estimate of the 2006 $F_{40\%}$ catch is moderate with a *CV* of 20%. The AMAK provides estimates of the standard errors for key output parameters, which we consider a good first approximation of assessment uncertainty and useful for evaluation of abundance patterns.

4) The recommended model configuration with a moderate prior on survey catchability (q) gives very conservative results relative to a model configuration with a fixed q=1.0 (Figure 15.11 in Lowe et al. 2004)

5) The model's predicted survey biomass trend is very conservative relative to the recent (2000, 2002, and 2004) observed bottom trawl survey biomass values (Figure 15.17).

6) The 2004 survey and fishery age composition data continue to show large numbers from the 1999 and 2000 year class, and the first appearance of the above average 2001 year class (Figures 5.4 and 15.9). The 2004 survey and fishery catch-at-age data are dominated by these three year classes. Currently we estimate the 1999 year class to be the third largest in the time series (but with a high degree of uncertainty: *CV*=30%).

We believe the current model configuration as implemented through AMAK with the ADMB software provides an improved assessment of BSAI Atka mackerel. In particular, we believe the important survey catchability and selectivity assumptions for describing the population dynamics of Atka mackerel are sensible from biological and mechanistic standpoints. Given the current stock size and the appearance of three and possibly four consecutive strong year classes, from a biological perspective (for Atka mackerel) the maximum permissible is acceptable.

The associated 2006 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.436 is 110,200 mt, which is our 2006 ABC recommendation for BSAI Atka mackerel.

The associated 2007 yield associated with the maximum permissible $F_{40\%}$ fishing mortality rate of 0.436 is 90,700 mt, which is our 2007 ABC recommendation for BSAI Atka mackerel.

The 2006 ABC recommendation represents an 11% decrease from the Council's 2005 ABC. Although the population is increasing, the estimated $F_{40\%}$ fishing mortality rate has decreased relative to last year. The recent fishery selectivity patterns indicate the fishery is harvesting greater numbers of younger, immature fish. The age at 50% selectivity for the estimated selectivity pattern used to determine $F_{40\%}$ in the 2004 assessment was about 4.5 years, which decreased to about 4 years in the current assessment. This compares with the age at 50% maturity of 3.6 years (Figure 15.11). Therefore, the current estimate of the $F_{40\%}$ fishing mortality rate is lower due to the shift in the average selectivity pattern used for projection purposes.

Area Allocation of Harvests

Amendment 28 of the Bering Sea/Aleutian Islands Fishery Management Plan divided the Aleutian subarea into 3 districts at 177° E and 177° W longitude, providing the mechanism to apportion the Aleutian Atka mackerel TACs. The Council used a 4-survey (1997, 2000, 2002, and 2004) weighted average to apportion the 2005 ABC. The rationale for the weighting scheme was described in Lowe et al. (2001).

The data used to derive the percentages for the weighting scheme are given below:

	1997	2000	2002	2004	2005 TAC Apportionment.	4-survey weighted average
541	12.3%	0.20%	24.7%	27.5%	19.8%	**19.8%**
542	51.0%	64.6%	42.3%	30.4%	42.6%	**42.6%**
543	36.4%	35.2%	33.0%	42.0%	37.6%	**37.6%**
Weights	8	12	18	27		

The apportionments of the 2006 and 2007 recommended ABCs based on the most recent 4-survey weighted average are:

	2006	2007
Eastern (541)	21,900 mt	18,000 mt
Central (542)	46,900 mt	38,700 mt
Western (543)	41,400 mt	34,200 mt
Total	110,200 mt	90,900 mt

15.9 Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2005 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2006 using a fixed value of natural mortality of 0.3, the schedules of selectivity estimated in the assessment (in this case the average of the 2000-2004 selectivities), and the best available estimate of total (year-end) catch for 2005 (in this case assumed equal to TAC). In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning (August) and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 500 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2006, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2006 recommended in the assessment to the *max* F_{ABC} for 2006. The 2006 catch was set equal to the 2005 level for projection purposes. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2001-2005 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2006 or 2) above ½ of its MSY level in 2006 and above its MSY level in 2016 under this scenario, then the stock is not overfished.)

Scenario 7: In 2006 and 2007, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2018 under this scenario, then the stock is not approaching an overfished condition.)

15.9.1 Status determination

The projections of female spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios are shown in Table 15.14. Harvest scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest scenarios #6 and #7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2006:

a) If spawning biomass for 2006 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b) If spawning biomass for 2006 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2006 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario #6 (Table 15.14). If the mean spawning biomass for 2016 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest scenario #7:

a) If the mean spawning biomass for 2008 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2008 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2008 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2018. If the mean spawning biomass for 2018 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

In the case of BSAI Atka mackerel, spawning biomass for 2006 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2008 in Table 15.14 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

15.10 Ecosystem Considerations

Atka mackerel spawning is demersal in moderately shallow waters; observations extend to approximately 100 m, but the lower depth limit for spawning and nesting of Atka mackerel in the Aleutian Islands is unknown. Female Atka mackerel deposit eggs in nests built and guarded by males on rocky substrates or on kelp in shallow water. Specific spawning and nesting sites have been observed off Seguam Island, and on offshore reefs and in and around island passes from Stalemate Bank to Akutan Pass (Lauth et al. *in reveiw*). Just based on depth considerations, there is likely some overlap of the fishery with the distribution of nesting sites, but the extent of the overlap with the spatial distribution of fishing impacted areas is unknown. However, overlap with spawning areas is likely to be low due to the following factors: 1) Atka mackerel are summer spawners and the directed fishery is conducted during 2 seasons which run January 20-April 15 (A season) and September 1-November (B season); 2) observations to date indicate that at least some spawning and nesting grounds occur in areas too shallow and rough for the fishery to operate; 3) there are trawl exclusion zones within 10 nm of all sea lion rookeries in the Aleutians and within 20 nm of the rookeries on Seguam and Agligadak Islands (in area 541); and 4) there are maximum seasonal catch percentage limits in place for sea lion critical habitat areas in the Central (542) and Western (543) Aleutians. These sea lion protection measures likely afford protection to several spawning grounds, and other spawning grounds which are not in closed areas but occur in untrawlable habitat are also afforded protection.

15.10.1 Ecosystem effects on BSAI Atka mackerel

Prey availability/abundance trends

Figure 15.21 shows the food web of the Aleutian Islands summer survey region, based on trawl survey and food habits data, with an emphasis on the predators and prey of Atka mackerel (see the current

Ecosystem Assessment's ecosystem modeling results section for a description of the methodology for constructing the food web).

Adult Atka mackerel in the Aleutians consume a variety of prey, but are primarily planktivorous. Food habits data from 1990-1994 indicates that Atka feed on calanoid copepods (40%) and euphausiids (25%) followed by squids (10%), juvenile pollock (6%), and finally a range of zooplankton including fish larvae (Fig. 15.22a). While Figure 15.22a shows an aggregate diet for the Aleutians management regions, Atka mackerel diet data also show a longitudinal gradient, with euphausiids dominating diets in the east and copepods and other zooplankton dominating in the west. Greater piscivory, especially on myctophids, occurs in the island passes (I. Ortiz, Univ. Wash., pers. comm.) No time series of abundance information is available for Aleutian Islands zooplankton, squid, or small forage fish.

Some preliminary results of sensitivity analysis suggest that Atka mackerel foraging in the Aleutian Islands may have a relatively strong competitive effect on walleye pollock distribution and abundance, as opposed to the Bering Sea where pollock may be more bottom-up (prey) controlled, or the Gulf of Alaska where pollock may be top-down (predator) controlled (K. Aydin, unpublished results). Since these sensitivity analyses treat the Aleutian Islands as a single "box model", it is possible that this is a mitigating or underlying factor for the geographical separation between Atka mackerel and pollock as a partitioning of foraging habitat.

Predator population trends

Atka mackerel are consumed by a variety of piscivores, including groundfish (e.g., Pacific cod and arrowtooth flounder, Livingston et al. unpubl. manuscr.), marine mammals (e.g., northern fur seals and Steller sea lions, Kajimura 1984, NMFS 1995, Sinclair and Zeppelin 2002), and seabirds (e.g., thick-billed murres, tufted puffins, and short-tailed shearwaters, Springer et al. 1999). Apportionment of Atka mackerel mortality between fishing, predation, and unexplained mortality, based on the consumption rates and food habits of predators averaged over 1990-1994 is shown in Figure 15.23. During these years, approximately 20% of Atka mackerel exploitation rate (as calculated by stock assessment) was due to the fishery, 62% due to predation, and 18% "unexplained", where "unexplained" is the difference between the stock assessment total mortality and the sum of fisheries exploitation and quantified predation. This unexplained mortality may be due to data uncertainty, or Atka mackerel mortality due to disease, migration, senescence, etc.

Of the 62% of mortality due to predation, a little less than half (25% of total) is due to Pacific cod predation, and one quarter (15% of total) due to Steller sea lion predation, with the remainder spread across a range of predators (Figure 15.22b), based on Steller sea lion diets published by Merrick et al. (1997) and summer fish food habits data from the REEM food habits database.

If converted to tonnages, this translates to 100,000-120,000 mt/year of Atka mackerel consumed by predatory fish (of which approximately 60,000 mt is consumed by Pacific cod), and 40,000-80,000 mt/year consumed by Steller sea lions during the early 1990s. Estimating the consumption of Atka mackerel by birds is more difficult to quantify due to data limitations: based on colony counts and residency times, predation by birds, primarily kittiwakes, fulmars, and puffins, on all forage and rockfish combined in the Aleutian Islands is at most 70,000 mt/year (Hunt et al. 2000). However, colony specific diet studies, for example for Buldir Island, indicate that the vast majority of prey found in these birds is sandlance, myctophids, and other smaller forage fish, with Atka mackerel never specifically identified as prey items, and "unidentified greenlings" occurring infrequently (Dragoo et al. 2001). The food web model's estimate, based on foraging overlap between species, puts the total Atka mackerel consumption by birds at less than 2,000 mt/year. While this might be an underestimate, it should be noted that most predation would occur on juveniles (<1year old) which is not counted in the stock assessment's total exploitation rates.

The abundance trends of Aleutian Islands Pacific cod and arrowtooth flounder is relatively stable. Northern fur seals are showing declines, and Steller sea lions have shown some slight increases. Declining trends in predator abundance could lead to possible decreases in Atka mackerel mortality. The population trends of seabirds are mixed, some increases, some decreases, and others stable. Seabird population trends could affect young-of-the-year mortality.

Changes in habitat quality

The 2000 Aleutian Islands summer bottom temperatures indicated that 2000 was the coldest year followed by summer bottom temperatures from the 2002 survey, which indicated the second coldest year (Figure 15.7). The 2004 AI summer bottom temperatures indicated that 2004 was an average year. This is a warming trend since the 2002 survey was the second coldest year after the 2000 survey. Bottom temps could possibly affect fish distribution, but there have been no directed studies, and there is no time series of data which demonstrates the effects on AI Atka mackerel.

15.10.2 Atka mackerel fishery effects on the ecosystem

Atka mackerel fishery contribution to bycatch

The levels of bycatch in the Atka mackerel fishery of prohibited species, forage fish, HAPC biota, marine mammals, birds, and other sensitive non-target species is relatively low except for the species which are noted in Table 15.15 and discussed below.

The Atka mackerel fishery has very low bycatch levels of some species of HAPC biota, e.g. seapens and whips. The bycatch of sponges and coral in the Atka mackerel fishery is variable. It is notable that in the last 5 years (2000-2004), the Atka mackerel fishery has taken on average about 45 and 43%, respectively of the total Aleutian Islands sponge and coral catches. It is unknown if the absolute levels of sponge and coral bycatch in the Atka mackerel fishery are of concern.

The bycatch of skates, which are considered a sensitive or vulnerable species based on life history parameters, is noted in Table 15.15. Skate bycatch in the Aleutian Islands Atka mackerel fishery is variable and has averaged 66 mt in the last 5 years (2000-2004). Over this same time period, the Atka mackerel fishery has taken an average of 28% of the total Aleutian Islands skate bycatch. It is unknown if the absolute levels of skate bycatch in the Atka mackerel fishery are of concern.

The bycatch of sculpin is notable and has averaged about 570 mt from 2000 to 2004. This level of bycatch represents an average of 61% of the total Aleutian Islands sculpin bycatch. It is unknown if the absolute levels of sculpin bycatch in the Atka mackerel fishery are of concern.

Concentration of Atka mackerel catches in time and space

Steller sea lion protection measures have spread out Atka mackerel harvests in time and space through the implementation of seasonal and area-specific TACs and harvest limits within sea lion critical habitat. However, this is still an issue of possible concern and research efforts continue to monitor and assess the availability of Atka mackerel biomass in areas of concern.

Atka mackerel fishery effects on amount of large size Atka mackerel

The numbers of large size Atka mackerel are largely impacted by highly variable year class strength rather than by the directed fishery. Year to year differences are attributed to natural fluctuations.

Atka mackerel fishery contribution to discards and offal production

There is no time series of the offal production from the Atka mackerel fishery. The Atka mackerel fishery has contributed on average about 700 mt and 12,100 mt of non-target and target species discards respectively, from 2000 to 2004. Most of the Atka mackerel fishery discards of target species are comprised of small Atka mackerel.

Atka mackerel fishery effects on Atka mackerel age-at-maturity and fecundity

The effects of the fishery on the age-at-maturity and fecundity of Atka mackerel are unknown. Studies were conducted to determine age-at-maturity (McDermott and Lowe 1997) and fecundity (McDermott 2003) of Atka mackerel. These are recent studies and there are no earlier studies for comparison on fish from an unexploited population. Further studies would be needed to determine if there have been changes over time and whether changes could be attributed to the fishery.

15.11 Data gaps and research priorities

No time series of information is available on copepod and euphausiid abundance in the Aleutian Islands. Regional and seasonal food habits data for Atka mackerel is also lacking. Studies to determine the impacts of environmental indicators such as temperature regime on Atka mackerel are needed. Further studies to determine whether there have been any changes in life history parameters over time (e.g. maturity-at-age, fecundity, weight- and length-at-age) would be informative. More information on Atka mackerel habitat preferences would be useful to improve our understanding of Essential Fish Habitat (EFH), and improve our assessment of the impacts to habitat due to fishing. Better habitat mapping of the Aleutian Islands would provide information for survey stratification and the extent of trawlable and untrawlable habitat.

Other areas of ongoing assessment research include: 1) a risk-averse evaluation of key model uncertainties related to natural mortality, fishery selectivity, and survey catchability, 2) exploration of differential natural mortality at age and over time, 3) collaboration with Fishery Interaction Team (FIT) personnel to utilize Atka mackerel tagging data to estimate length-specific commercial selectivity and examine independent estimates of natural mortality, and 4) continued evaluation of model sensitivity to a number of input specifications.

15.12 Summary

Natural mortality = 0.3

2006 (Tier 3a)			
Maximum permissible ABC:	$F_{40\%}$ = 0.436	yield =	110,200 mt
Recommended ABC:	$F_{40\%}$ = 0.436	yield =	110,200 mt
Overfishing (OFL):	$F_{35\%}$ = 0.533	yield =	130,000 mt
Equilibrium female spawning biomass			
$B_{100\%}$ =	239,700 mt		

$B_{40\%}$ = 95,900 mt

$B_{35\%}$ = 83,900 mt

Projected 2006 biomass

Age 3+ biomass = 446,200 mt

Female spawning biomass = 155,800 mt

15.13 Acknowledgements

We thank the AFSC survey personnel for the collection of data and providing the biomass estimates. We are especially grateful to all the fishery observers of the North Pacific Groundfish Observer Program who collect vital data for the stock assessments. We also thank the staff of the AFSC Age and Growth Unit for the ageing of otoliths used to determine the age compositions in the assessment.

15.14 Literature cited

Alverson, D.L., and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer 36:133-143.

Anderl, D.M., A. Nishimura, and S.A. Lowe. 1996. Is the first annulus on the otolith of the Atka mackerel, *Pleurogrammus monopterygius*, missing? Fish. Bull. 94:163-169.

Barbeaux, S., J. Ianelli, and E. Brown. 2003. Aleutian Islands walleye pollock SAFE. Appendix to Eastern Bering Sea walleye pollock stock assessment *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Barbeaux, S., J. Ianelli, and E. Brown. 2004. Stock assessment of Aleutian Islands region pollock. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Canino, M., I. Spies, and S. Lowe. *In review*. High resolution of population structure in Atka mackerel, *Pleurogrammus monopterygius*, in the Aleutian archipelago. Trans. Amer. Fish. Soc.

Charnov, E.L. 1993. Life history invariants some explorations of symmetry in evolutionary ecology. Oxford University Press Inc., New York. 167p.

Dragoo, D.E., G.V. Byrd, and D.B. Irons. 2001. Breeding status, population trends, and diets of seabirds in Alaska, 2000. U.S. Fish and Wildl. Serv. Report AMNWR 01/07.

Fournier, D. 1998. An Introduction to AD model builder for use in nonlinear modeling and statistics. Otter Research Ltd. PO Box 2040, Sidney BC V8L3S3, Canada, 53p.

Fournier, D., and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. Can. J. Fish. Aquat. Sci. 49: 922-930.

Fritz, L. W. 1993. Trawl locations of walleye pollock and Atka mackerel fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska from 1977-1992. AFSC Processed Report 93-08, NMFS, 7600 Sand Point Way, NE, Seattle, WA 98115. 162 pp.

Gorbunova, N.N. 1962. Razmnozhenie i razvite ryb semeistva terpugovykh (Hexagrammidae) (Spawning and development of greenlings (family Hexagrammidae)). Tr. Inst. Okeanol., Akad. Nauk SSSR 59:118-182. In Russian. (Trans. by Isr. Program Sci. Trans., 1970, p. 121-185 in T.S. Rass (editor), Greenlings: taxonomy, biology, interoceanic transplantation; available from the U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA., as TT 69-55097).

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Hunt, G.L. Jr., H. Kato, and S.M. McKinnell [eds.] 2000. Predation by marine birds and mammals in the subarctic north Pacific Ocean. North Pacific Marine Science Organization (PICES) Scientific Report #25. 165 p.

Ianelli, J.N. and D.A. Fournier. 1998. Alternative age-structured analyses of the NRC simulated stock assessment data. In Restrepo, V.R. [ed.]. Analyses of simulated data sets in support of the NRC study on stock assessment methods. NOAA Tech. Memo. NMFS-F/SPO-30. 96 p.

Kajimura, H. 1984. Opportunistic feeding of the northern fur seal *Callorhinus ursinus*, in the eastern north Pacific Ocean and eastern Bering Sea. NOAA Tech. Rept. NMFS SSRF-779. USDOC, NOAA, NMFS, 49 pp.

Kendall, A.W., and J.R. Dunn. 1985. Ichthyoplankton of the continental shelf near Kodiak Island, Alaska. U.S. Department of Commerce, NOAA Technical Report NMFS 20, 89 p.

Kimura, D.K. 1989. Variability in estimating catch-in-numbers-at-age and its impact on cohort analysis. P.57-66, In Effects of ocean variability on recruitment and evaluation of parameters used in stock assessment models, R.J. Beamish and G.A. McFarlane (editors), Can. Spec. Pub. Fish. Aquat. 108.

Kimura D.K. and L.L. Ronholt. 1988. In R.G. Bakkala (editor), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1987, p. 143-171. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-139.

Kimura, D.K., and S. Chikuni. 1987. Mixtures of empirical distributions: an iterative application of the age-length key. Biometrics 43: 23-35.

Lauth,R.R., S.W. McEntire, and H.H. Zenger. In review. Geographic distribution, depth range, and description of Atka mackerel (*Pleurogrammus monopterygius*) nesting habitat in Alaska. Submitted to Alaska Fishery Research Bulletin.

Lee, J.U. 1985. Studies on the fishery biology of the Atka mackerel *Pleurogrammus monopterygius* (Pallas) in the north Pacific Ocean. Bull. Fish. Res. Dev. Agency, 34, pp.65-125.

Levada, T.P. 1979. Comparative morphological study of Atka mackerel. Pac. Sci. Res. Inst. Fish. Oceanogr. (TINRO), Vladivostok, U.S.S.R., Unpublished manuscript.

Livingston, P.A., M-S. Yang and G.M. Lang. Unpublished manuscript. Comparison of the role of walleye pollock in groundfish food webs of the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska. NMFS. Alaska Fisheries Science Center, 7600 Sand Point Way NE., Seattle, WA 98115.

Lowe, S. A. 1991. Atka Mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1992. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S. A. 1992. Atka Mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1993. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A., D.M. Van Doornik, and G.A. Winans. 1998. Geographic variation in genetic and growth patterns of Atka mackerel, *Pleurogrammus monopterygius* (Hexagrammidae), in the Aleutian archipelago. Fish. Bull. U.S. 96:502-515.

Lowe, S., J. Ianelli, H. Zenger, and R. Lauth. 2003. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S., J. Ianelli, H. Zenger, K. Aydim, and R. Lauth. 2004. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S., J. Ianelli, H. Zenger, and R. Reuter. 2002. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A. and L.W. Fritz. 1996. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1997. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A. and L.W. Fritz. 1997. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1999. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Lowe, S.A., R.F. Reuter and H. Zenger. 2001. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

McDermott, S. F. 2003. Improving abundance estimation of a patchily distributed fish, Atka mackerel (*Pleurogrammus monopterygius*). Dissertation, University of Washington, 150p .

McDermott, S. F., L. W. Fritz, and V. Haist. 2005. Estimating movement and abundance of Atka mackerel (*Pleurogrammus monopterygius*) with tag-release data. Fish. Oceanogr. 14, (Suppl 1), 113-.

McDermott, S.F. and S.A. Lowe. 1997. The reproductive cycle of Atka mackerel, *Pleurogrammus monopterygius*, in Alaska waters. Fish. Bull. U.S. 95:231-333.

Medveditsyna, A.V. 1962. Data on the Atka mackerel (*Pleurogrammus monopterygius* (Pallas)). Trudy Instituta Okeanologii Akademiya Nauk SSSR 59:104-106. In Russian. (Translated by the Israel Program for Scientific Translations, 1970. Pages 104-106 in T.S. Rass (editor), Greenlings: taxonomy, biology, interoceanic transplantation; available from the U.S. Department of Commerce, National Technical Information Services, Springfield, Virginia, as TT 69-55097).

Merrick, R.L., M.K. Chumbley, and G.V. Byrd. 1997. Diet diversity of Steller sea lions (*Eumetopias jubatus*) and their population decline in Alaska: a potential relationship. Can. J. Fish. Aquat. Sci. 54:1342-1348.

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. In E. Edwards and B. Megrey (eds.) Mathematical analysis of fish stock dynamics: reviews and current applications. Amer. Fish. Soc. Symposium 6:66-82.

Methot, R.D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. INPFC Bull. 50:259-277.

Nichol D.G., Somerton D.A. 2002. Diurnal vertical migration of the Atka mackerel *Pleurogrammus monopterygius* as shown by archival tags. Mar Ecol Prog Ser 239: 193-207.

NMFS. 1995. Status review of the Unites States Steller sea lion (*Eumetopias jubatus*) population. National Marine Mammal Laboratory, Alaska Fishery Science Center, National Marine Fisheries Service, 7600 Sand Point Way, NE, Seattle, WA 98115.

Pauly, D. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. 1980. J. Cons. Int. Explor. Mer 39(2):175-192.

Press, W.H., S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery. 1992. Numerical recipes in C. Second ed. Cambridge University Press. 994p.

Rikhter, V.A., and V.N. Efanov. 1976. On one of the approaches to estimation of natural mortality of fish populations. ICNAF Res. Doc. 76/VI/8. Serial N. 3777. 13p.

Roff, D.A. 1986. The evolution of life history parameters in teleosts. Can. J. Fish. Aquat. Sci. 41:989-1000.

Rutenberg, E.P. 1962. Survey of the fishes family Hexagrammidae. Trudy Instituta Okeanologii Akademiya Nauk SSSR 59:3-100. In Russian. (Translated by the Israel Program for Scientific Translations, 1970. Pages 1-103 in T.S. Rass (editor), Greenlings: taxonomy, biology, interoceanic transplantation; available from the U.S. Department of Commerce, National Technical Information Services, Springfield, Virginia, as TT 69-55097).

Sinclair E.H. and T.K. Zeppelin 2002. Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). Journal of Mammalogy 83(4).

Springer, A.M., J.F. Piatt, V.P. Shuntov, G.B. Van Vliet, V.L. Vladimirov, A.E. Kuzin, A.S. Perlov. 1999. Prog. in Oceanogr. 43(1999)443-487.

Yang, M-S. 1999. The trophic role of Atka mackerel, *Pleurogrammus monopterygius*, in the Aleutian Islands area. Fishery Bulletin 97(4):1047-1057.

Zolotov, O.G. 1981. On sexual dimorphism in the Atka mackerel, *Pleurogrammus monopterygius*. Journal of Ichthyology 21(2): 253-257.

Zolotov, O.G. 1993. Notes on the reproductive biology of *Pleurogrammus monopterygius* in Kamchatkan waters. J. of Ichthy. 33(4), pp. 25-37.

15.15 Tables

Table 15.1. Atka mackerel catches (including discards and CDQ catches) by region and corresponding Acceptable Biological Catches (ABC), and Total Allowable Catches (TAC) set by the North Pacific Fishery Management Council from 1978 to the present. Catches, ABCs, and TACs are in mt.

	Eastern Bering Sea				Aleutian Islands Region				BSAI		
Year	Foreign	Domestic		Total	Foreign	Domestic		Total			
		JVP	DAP			JVP	DAP		Total	ABC	TAC
1977	0	0	0	a	21,763	0	0	21,763	21,763	b	b
1978	831	0	0	831	23,418	0	0	23,418	24,249	24,800	24,800
1979	1,985	0	0	1,985	21,279	0	0	21,279	23,264	24,800	24,800
1980	4,690	265	0	4,955	15,533	0	0	15,533	20,488	24,800	24,800
1981	3,027	0	0	3,027	15,028	1,633	0	16,661	19,688	24,800	24,800
1982	282	46	0	328	7,117	12,429	0	19,546	19,874	24,800	24,800
1983	140	1	0	141	1,074	10,511	0	11,585	11,726	25,500	24,800
1984	41	16	0	57	71	35,927	0	35,998	36,055	25,500	23,130
1985	1	3	0	4	0	37,856	0	37,856	37,860	37,700	37,700
1986	6	6	0	12	0	31,978	0	31,978	31,990	30,800	30,800
1987	0	12	0	12	0	30,049	0	30,049	30,061	30,800	30,800
1988	0	43	385	428	0	19,577	2,080	21,656	22,084	21,000	21,000
1989	0	56	3,070	3,126	0	0	14,868	14,868	17,994	24,000	20,285
1990	0	0	480	480	0	0	21,725	21,725	22,205	24,000	21,000
1991	0	0	2,596	2,596	0	0	24,144	24,144	26,740	24,000	24,000
1992	0	0	2,610	2,610	0	0	47,425	47,425	50,035	43,000	43,000
1993	0	0	213	213	0	0	65,524	65,524	65,737	117,100	64,000
1994	0	0	189	189	0	0	69,401	69,401	69,590	122,500	68,000
1995	0	0	a	a	0	0	81,554	81,554	81,554	125,000	80,000
1996	0	0	a	a	0	0	103,943	103,943	103,943	116,000	106,157
1997	0	0	a	a	0	0	65,845	65,845	65,845	66,700	66,700
1998	0	0	a	a	0	0	58,310	58,310	58,310	64,300	64,300
1999	0	0	a	a	0	0	56,231	56,231	56,231	73,300	66,400
2000	0	0	a	a	0	0	47,227	47,227	47,227	70,800	70,800
2001	0	0	a	a	a	0	61,612	61,612	61,612	69,300	69,300
2002	0	0	a	a	a	0	45,594	45,594	45,594	49,000	49,000
2003	0	a	a	a	a	0	54,890	54,890	54,890	63,000	60,000
2004	0	a	a	a	a	0	60,457	60,457	60,457	66,700	63,000
2005[c]	0	a	a	a	a	0	60,459	60,459	60,459	124,000	63,000

Catch table footnotes:

a) Eastern Bering Sea catches included with Aleutian Islands.
b) Atka mackerel was not a reported species group until 1978
c) 2005 data as of 10/15/05 from NMFS Alaska Regional Office Home Page. Available at http://www.fakr.noaa.gov/2005/car110_bsai_with_cdq.pdf

Table 15.2 Research catches (mt) of Atka mackerel from NMFS trawl surveys in the Aleutian Islands.

Year	Catch
1980	47.9
1981	3.9
1982	0.9
1983	151.4
1986	130.2
1991	77.1
1994	146.5
1997	85.2

Table 15.3 Estimated catch-in-numbers at age (in millions) of Atka mackerel from the Aleutian Islands. These data were used to tune the age-structured analysis.

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	6.83	31.52	20.06	15.11	1.22	0.39	0.20	---	---	---	---	---	---	---
1978	2.70	60.16	15.57	9.22	3.75	0.59	0.34	0.11	---	---	---	---	---	---
1979	0.01	4.48	26.78	13.00	2.20	1.11	---	---	---	---	---	---	---	---
1980	---	12.68	5.92	7.22	1.67	0.59	0.24	0.13	---	---	---	---	---	---
1981	---	5.39	17.11	0.00	1.61	8.10	---	---	---	---	---	---	---	---
1982	---	0.19	2.63	25.83	3.86	0.68	---	---	---	---	---	---	---	---
1983	---	1.90	1.43	2.54	10.60	1.59	---	---	---	---	---	---	---	---
1984	0.09	0.98	7.30	7.07	10.79	21.78	2.21	0.96	---	---	---	---	---	---
1985	0.63	15.97	8.79	9.43	6.01	5.45	11.69	1.26	0.27	---	---	---	---	---
1986	0.37	11.45	6.46	4.42	5.34	4.53	5.84	9.91	1.04	0.85	---	---	---	---
1987	0.56	10.44	7.60	4.58	1.89	2.37	2.19	1.71	6.78	0.53	0.22	---	---	---
1988	0.40	9.97	22.49	6.15	1.80	1.54	0.63	0.96	0.20	0.44	0.04	---	---	---
1989[a]														
1990	---	4.05	12.06	6.79	2.49	0.89	0.19	0.13	0.05	0.02	0.04	0.16	0.03	---
1991	---	1.96	5.58	10.11	5.90	3.06	1.29	0.27	0.41	0.40	0.09	---	---	---
1992[a]														
1993[a]														
1994	0.03	9.57	6.95	24.00	39.77	4.57	9.42	6.59	4.26	0.61	0.27	0.00	0.00	0.03
1995	0.24	19.04	41.27	9.78	14.85	27.63	3.57	4.01	5.36	2.04	---	---	---	---
1996	0.03	3.45	65.69	22.31	12.77	20.87	31.93	3.02	3.60	2.64	0.51	0.05	---	---
1997[a]														
1998	---	11.34	18.95	17.30	31.93	11.65	4.15	3.83	5.58	0.47	0.85	0.76	---	---
1999	1.22	1.02	38.78	9.74	7.77	11.17	4.49	1.57	1.06	1.13	0.16	0.13	---	---
2000	0.56	7.74	5.11	23.73	6.94	3.80	7.41	1.89	0.81	0.53	0.32	0.32	---	---
2001	1.55	20.31	11.06	7.17	23.74	6.70	3.98	3.80	0.72	0.33	0.078	0.10	---	---
2002	2.16	24.00	24.93	7.05	3.56	15.23	2.94	1.55	2.42	0.31	0.28	---	---	---
2003	1.08	23.15	57.74	18.29	4.89	2.81	5.99	0.57	0.45	0.68	0.19	---	---	---
2004	0.08	24.26	34.79	47.59	13.25	2.07	1.44	2.01	---	---	0.38	---	---	---

[a] Too few fish were sampled for age structures in 1989, 1992, 1993, and 1997 to construct age-length keys (see Section 15.3.1).

Table 15.4 Atka mackerel estimated biomass in metric tons from the bottom trawl survey, by subregion, depth interval, and survey year, with the corresponding coefficients of variation.

		Biomass			Coefficient of variation		
Area	Depth (m)	1980	1983	1986	1980	1983	1986
Aleutian	1-100	48,306	140,552	450,869			
	101-200	144,431	162,399	93,501			
	201-300	4,296	3,656	331			
	301-500	483	172	16			
	501-900	13	1	37			
	Total	197,529	306,780	544,754	0.42	0.22	0.63
Southwest Aleutian	1-100	95	15,321	418,271			
	101-200	75,857	120,991	51,312			
	201-300	619	2,304	122			
	301-500	105	172	14			
	501-900	9	1	0			
	Total	76,685	138,789	469,719	0.57	0.36	0.73
Southeast Aleutian	1-100	0	65,814	33			
	101-200	21,153	854	89			
	201-300	115	202	3			
	301-500	16	0	0			
	501-900	0	0	0			
	Total	21,284	66,870	125	0.86	0.01	0.64
Northwest Aleutian	1-100	0	41,235	32,564			
	101-200	382	5,571	211			
	201-300	2,524	34	0			
	301-500	0	0	0			
	501-900	4	0	0			
	Total	2,910	46,840	32,775	0.84	0.64	0.65
Northeast Aleutian	1-100	48,211	18,182	1			
	101-200	47,039	34,983	44,889			
	201-300	1,038	1,116	206			
	301-500	362	0	2			
	501-900	0	0	37			
	Total	96,650	54,281	42,135	0.69	0.57	0.46

Table 15.5 Atka mackerel biomass (mt), and the percentage distribution and coefficients of variation (*CV*) by management area from the bottom trawl surveys in the Aleutian Islands in 1991, 1994, 1997, 2000, 2002, and 2004. Biomass is also reported by survey depth interval.

Area	Depth (m)	Biomass (mt)					
		1991	1994	1997	2000	2002	2004
Aleutian	1-100	429,826	145,000	188,504	145,001	330,891	394,594
Islands	101-200	293,554	455,452	177,663	357,138	393,055	485,428
	201-300	538	1,688	127	8,635	48,630	7,474
	301-500	-	22	20	82	221	288
	Total	723,918	602,161	366,314	510,857	772,798	886,783
	Area % of Total	100%	100%	100%	100%	100%	100%
	CV	15%	33%	29%	28%	20%	17%
Western	1-100	168,968	93,847	90,824	106,168	51,921	140,669
543	101-200	185,748	214,228	43,478	65,600	154,820	226,043
	201-300	304	1,656	63	7,912	48,366	6,033
	301-500	-	6	-	-	7.6	36
	Total	355,020	309,737	134,364	179,680	255,115	372,782
	Area % of Total	49.0%	51.4%	36.7%	35.2%	33.0%	42.0%
	CV	18%	55%	56%	51%	31%	24%
Central	1-100	187,194	50,513	70,458	38,805	126,811	198,501
542	101-200	104,413	33,517	116,295	290,766	199,743	70,793
	201-300	71	13	53	674	169	470
	301-500	-	3	6	9	143	194
	Total	291,679	84,046	186,813	330,255	326,866	269,958
	Area % of Total	40.3%	14.0%	51.0%	64.6%	42.3%	30.4%
	CV	18%	48%	36%	34%	24%	34%
Eastern	1-100	73,663	641	27,222	29	152,159	54,424
541	101-200	3,392	207,707	17,890	772	38,492	188,592
	201-300	163	19	11	48	94	971
	301-500	-	12	14	73	71	57
	Total	77,218	208,379	45,137	922	190,817	244,043
	Area % of Total	10.7%	34.6%	12.3%	0.2%	24.7%	27.5%
	CV	83%	44%	68%	74%	58%	33%
Bering Sea	1-100	47	66,562	95,672	1,853	59,682	127,896
	101-200	3	30	9	187	103	142,616
	201-300	11	3	-	4	98	39
	301-500	-	8	-	-	-	4
	Total	61	66,603	95,680	2,044	59,883	267,556
	CV	37%	99%	99%	87%	99%	43%

Table 15.6 Mean weight-at-age (kg) and length-at-age values (cm) for Atka mackerel from the Aleutian trawl surveys and the commercial fishery. The survey vectors are derived from data from the years 1986, 1991, and 1994; the fishery vectors are derived from data from the years 1990 to 1996.

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Survey														
(kg)	0.184	0.398	0.549	0.656	0.732	0.785	0.823	0.85	0.869	0.882	0.892	0.899	0.903	0.907
(cm)	25.15	30.92	34.65	37.05	38.59	39.59	40.23	40.65	40.92	41.09	41.20	41.27	41.32	41.35
Fishery														
(kg)	0.128	0.421	0.66	0.756	0.794	0.81	0.816	0.818	0.819	0.82	0.82	0.82	0.82	0.82
(cm)	22.94	31.91	36.49	38.84	40.04	40.66	40.97	41.13	41.21	41.26	41.28	41.29	41.29	41.30

Table 15.7 Schedules of age and length specific maturity of Atka mackerel from McDermott and Lowe (1997) by Aleutian Islands subareas. Eastern - 541, Central - 542, and Western - 543.

	INPFC Area				Proportion
Length (cm)	541	542	543	Age	mature
25	0	0	0	1	0
26	0	0	0	2	0.04
27	0	0.01	0.01	3	0.22
28	0	0.02	0.02	4	0.69
29	0.01	0.04	0.04	5	0.94
30	0.01	0.07	0.07	6	0.99
31	0.03	0.14	0.13	7	1
32	0.06	0.25	0.24	8	1
33	0.11	0.4	0.39	9	1
34	0.2	0.58	0.56	10	1
35	0.34	0.73	0.72		
36	0.51	0.85	0.84		
37	0.68	0.92	0.92		
38	0.81	0.96	0.96		
39	0.9	0.98	0.98		
40	0.95	0.99	0.99		
41	0.97	0.99	0.99		
42	0.99	1	1		
43	0.99	1	1		
44	1	1	1		
45	1	1	1		
46	1	1	1		
47	1	1	1		
48	1	1	1		
49	1	1	1		
50	1	1	1		

Table 15.8. Estimates of key results from AMAK for Aleutian Islands Atka mackerel from the current assessment and last year's (2004) assessment. Coefficients of variation (*CV*) for some key reference values appearing directly above, are given in parentheses.

Assessment Model	Current	2004
Model setup		
Survey catchability	1.429	1.405
Steepness	0.800	0.800
SigmaR	0.6	0.6
Natural mortality	0.300	0.300
Fishery Average Effective *N*	115	115
Survey Average Effective *N*	48	51
RMSE Survey	0.278	0.281
-log Likelihoods		
Number of Parameters	378	374
Survey index	3.16	2.34
Catch biomass	0.06	0.06
Fishery age comp	160.08	155.54
Survey age comp	40.35	35.09
Sub total	203.65	193.03
-log Penalties		
Recruitment	7.036	8.013
Selectivity constraint	120.721	113.496
Fishing mortality penalty	0.000	0.000
Prior	2.464	2.117
Total	333.870	316.656
Fishing mortalities (full selection)		
F 2005	0.131	
F 2005/*F* 40%	0.499	
F 40%	0.262	0.403
CV	(31%)	(42%)
*F*35%	0.316	0.497
CV	(32%)	(43%)
Stock abundance		
Initial Biomass (mt, 1977)	299,360	291,350
CV	(17%)	(17%)
2005 total biomass (mt)	649,210	
CV	(17%)	
2005 Age 3+ biomass (mt)	534,805	
1999 year class (1000's at age 1)	1,121	1,298
CV	(30%)	(32%)
2001 year class (1000's at age 1)	716	
CV	(47%)	
Recruitment Variability	0.594	0.604
Projected catch (unadjusted)		
F 40% 2006 catch (mt)	103,600	
CV	(20%)	
F 35% 2006 catch (mt)	121,370	
CV	(20%)	

Table 15.9. 1977-2005 estimates of Atka mackerel fishery (over time) and survey selectivity at age for Model 4. These are full-selection (maximum = 1.0) estimates.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	0.02	0.11	0.41	0.88	1.00	0.72	0.44	0.28	0.20	0.16	0.16	0.16	0.16	0.16	0.16
1978	0.02	0.11	0.49	0.82	1.00	0.84	0.57	0.36	0.24	0.19	0.19	0.19	0.19	0.19	0.19
1979	0.01	0.05	0.26	0.81	1.00	0.84	0.58	0.37	0.24	0.19	0.19	0.19	0.19	0.19	0.19
1980	0.01	0.06	0.22	0.62	1.00	0.95	0.78	0.52	0.32	0.23	0.23	0.23	0.23	0.23	0.23
1981	0.01	0.04	0.15	0.29	0.38	0.64	1.00	0.55	0.27	0.17	0.17	0.17	0.17	0.17	0.17
1982	0.01	0.03	0.10	0.34	0.90	1.00	0.65	0.38	0.24	0.19	0.19	0.19	0.19	0.19	0.19
1983	0.01	0.04	0.16	0.39	0.70	1.00	0.86	0.48	0.29	0.22	0.22	0.22	0.22	0.22	0.22
1984	0.01	0.03	0.14	0.43	0.78	1.00	0.91	0.62	0.39	0.28	0.28	0.28	0.28	0.28	0.28
1985	0.01	0.06	0.41	0.85	1.00	0.99	0.90	0.76	0.61	0.50	0.50	0.50	0.50	0.50	0.50
1986	0.01	0.04	0.24	0.51	0.72	0.85	0.97	1.00	0.82	0.62	0.62	0.62	0.62	0.62	0.62
1987	0.01	0.04	0.24	0.57	0.78	0.87	0.94	1.00	0.96	0.90	0.90	0.90	0.90	0.90	0.90
1988	0.01	0.05	0.31	0.98	1.00	0.86	0.82	0.76	0.71	0.64	0.64	0.64	0.64	0.64	0.64
1989	0.01	0.04	0.20	0.58	0.94	1.00	0.88	0.74	0.65	0.60	0.60	0.60	0.60	0.60	0.60
1990	0.00	0.03	0.23	0.80	1.00	0.78	0.64	0.56	0.53	0.52	0.52	0.52	0.52	0.52	0.52
1991	0.00	0.02	0.09	0.42	0.89	1.00	0.84	0.70	0.60	0.57	0.57	0.57	0.57	0.57	0.57
1992	0.01	0.03	0.10	0.31	0.67	0.95	1.00	0.95	0.90	0.86	0.86	0.86	0.86	0.86	0.86
1993	0.01	0.03	0.10	0.27	0.56	0.88	1.00	0.98	0.97	0.98	0.98	0.98	0.98	0.98	0.98
1994	0.01	0.02	0.10	0.32	0.65	0.84	0.87	0.96	1.00	0.98	0.98	0.98	0.98	0.98	0.98
1995	0.00	0.03	0.14	0.48	0.64	0.69	0.78	0.84	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.00	0.02	0.10	0.35	0.53	0.71	0.90	1.00	0.94	0.90	0.90	0.90	0.90	0.90	0.90
1997	0.01	0.02	0.09	0.26	0.51	0.76	0.89	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.02	0.09	0.33	0.61	0.79	0.88	0.94	0.98	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.03	0.14	0.50	0.71	0.81	0.85	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.03	0.17	0.47	0.74	0.87	0.94	1.00	0.97	0.93	0.93	0.93	0.93	0.93	0.93
2001	0.00	0.02	0.15	0.45	0.76	0.91	1.00	0.96	0.85	0.78	0.78	0.78	0.78	0.78	0.78
2002	0.00	0.03	0.13	0.37	0.62	0.84	1.00	0.93	0.81	0.72	0.72	0.72	0.72	0.72	0.72
2003	0.01	0.04	0.23	0.60	0.76	0.89	1.00	0.99	0.90	0.84	0.84	0.84	0.84	0.84	0.84
2004	0.01	0.06	0.29	0.74	1.00	0.96	0.94	0.94	0.91	0.89	0.89	0.89	0.89	0.89	0.89
2005	0.01	0.06	0.29	0.74	1.00	0.96	0.94	0.94	0.91	0.89	0.89	0.89	0.89	0.89	0.89
Avg. 2000-2004	0.01	0.04	0.20	0.54	0.79	0.92	1.00	0.99	0.91	0.85	0.85	0.85	0.85	0.85	0.85
Survey	0.03	0.15	0.58	0.95	1.00	1.06	1.04	0.99	0.89	0.83	0.79	0.76	0.76	0.76	0.76

Table 15.10. Estimated Atka mackerel numbers at age in thousands, 1977-2005.

Year	1	2	3	4	5	6	7	8	9	10+	Total	% of 10+
1977	212	229	182	50	38	20	19	17	14	65	847	8%
1978	1,165	156	166	123	30	22	13	13	12	57	1,756	3%
1979	333	860	113	111	77	18	14	8	9	49	1,593	3%
1980	212	246	630	80	71	47	12	9	6	41	1,354	3%
1981	246	157	181	453	54	46	31	8	6	33	1,216	3%
1982	160	182	116	131	321	38	31	20	5	29	1,032	3%
1983	239	119	134	85	94	220	26	21	14	25	978	3%
1984	329	177	88	99	62	67	155	18	16	28	1,038	3%
1985	510	243	130	63	68	40	42	97	12	31	1,235	2%
1986	484	377	178	89	40	41	24	26	62	28	1,348	2%
1987	639	358	277	125	59	25	25	14	15	57	1,595	4%
1988	392	473	263	196	84	38	16	16	9	45	1,532	3%
1989	1,132	290	349	189	132	56	26	11	11	38	2,233	2%
1990	522	838	214	254	134	91	38	18	8	34	2,151	2%
1991	271	387	619	156	176	91	63	27	13	30	1,832	2%
1992	546	201	286	454	110	119	61	43	19	29	1,868	2%
1993	811	404	148	208	318	72	74	38	27	30	2,130	1%
1994	292	600	297	107	144	206	43	43	22	33	1,787	2%
1995	319	216	442	214	73	90	122	25	25	31	1,557	2%
1996	723	236	158	312	134	43	52	69	14	30	1,770	2%
1997	141	534	173	111	191	74	22	24	30	20	1,320	1%
1998	239	104	392	123	74	114	40	11	12	24	1,134	2%
1999	657	177	76	280	81	43	63	21	6	18	1,423	1%
2000	1,121	486	130	54	177	48	25	35	12	13	2,101	1%
2001	686	830	358	92	35	106	27	14	20	14	2,181	1%
2002	716	507	609	248	56	19	53	13	7	17	2,246	1%
2003	256	530	373	433	164	34	11	29	7	14	1,852	1%
2004	250	189	389	264	284	104	21	6	18	14	1,540	1%
2005	287	185	139	275	173	179	66	13	4	20	1,342	1%

Table 15.11. Estimates of Atka mackerel biomass in mt with approximate lower and upper 95% confidence bounds for age 1+ biomass (labeled as LCI and UCI). Also included are age 3+ and female spawning biomass in mt from the current assessment compared to last year's (2004) assessment.

	Current assessment age 1+ biomass (mt)			Age 3+ biomass (mt)		Female spawning biomass (mt)	
Year	Estimate	LCI	UCI	Current	2004	Current	2004
1977	299,360	198,938	399,782	239,168	231,694	74,143	71,070
1978	404,490	272,876	536,104	250,738	243,781	70,176	67,552
1979	401,890	267,384	536,396	238,842	232,599	73,903	71,459
1980	516,240	347,046	685,434	433,800	425,241	78,115	75,776
1981	561,230	380,064	742,396	456,323	447,516	96,018	93,602
1982	515,970	350,694	681,246	427,080	418,621	147,158	144,131
1983	467,930	321,274	614,586	395,240	387,064	161,611	158,365
1984	433,820	304,258	563,382	354,018	346,635	148,877	145,791
1985	408,760	289,706	527,814	309,828	303,197	126,862	123,986
1986	406,630	292,814	520,446	293,333	287,163	102,936	100,357
1987	464,670	349,582	579,758	330,901	325,513	89,752	87,455
1988	503,020	389,592	616,448	368,183	363,742	92,526	90,448
1989	635,450	523,234	747,666	442,353	438,661	110,432	108,639
1990	669,680	564,350	775,010	460,612	457,895	133,245	131,781
1991	752,800	648,696	856,904	623,322	620,939	156,321	155,162
1992	801,620	698,018	905,222	647,953	645,980	175,669	174,791
1993	767,390	669,820	864,960	573,659	572,049	208,718	207,974
1994	689,030	597,630	780,430	539,757	538,184	204,069	203,415
1995	678,150	582,798	773,502	572,339	571,342	172,750	172,181
1996	643,440	542,786	744,094	488,616	488,291	157,558	157,064
1997	509,470	414,708	604,232	389,284	390,089	146,891	146,594
1998	500,900	399,160	602,640	427,746	434,177	124,265	124,295
1999	488,620	382,522	594,718	356,850	364,898	112,493	113,381
2000	505,240	390,326	620,154	302,504	317,398	116,695	119,300
2001	556,890	423,230	690,550	355,178	404,516	100,714	104,944
2002	686,980	509,236	864,724	502,929	589,473	87,937	97,318
2003	737,060	536,660	937,460	570,292	640,046	115,451	137,041
2004	732,020	515,480	948,560	611,219	568,079	166,179	204,418
2005	649,210	440,070	858,350	534,805	485,719	186,536	
2006				446,225		155,800	

Table 15.12 Estimates of age-1 Atka mackerel recruitment (1000's of recruits).

	Age 1 Recruits	
Year	Current	2004
1977	212	209
1978	1165	1,149
1979	333	328
1980	212	208
1981	246	240
1982	160	158
1983	239	236
1984	329	325
1985	510	508
1986	484	484
1987	639	638
1988	392	393
1989	1132	1,130
1990	522	522
1991	271	271
1992	546	545
1993	811	812
1994	292	294
1995	319	324
1996	723	748
1997	141	148
1998	239	274
1999	657	820
2000	1121	1,298
2001	686	635
2002	716	253
2003	256	299
2004	250	
Ave 78-05	496	
Med 78-04	392	

Table 15.13. Estimates of full-selection fishing mortality rates and exploitation rates for Atka mackerel.

Year	*F*[a]	Catch/Biomass Rate[b]
1977	0.232	0.091
1978	0.202	0.097
1979	0.192	0.097
1980	0.133	0.047
1981	0.155	0.043
1982	0.086	0.047
1983	0.052	0.030
1984	0.185	0.102
1985	0.200	0.122
1986	0.214	0.109
1987	0.183	0.091
1988	0.098	0.060
1989	0.081	0.041
1990	0.082	0.048
1991	0.104	0.043
1992	0.182	0.077
1993	0.245	0.115
1994	0.267	0.129
1995	0.355	0.142
1996	0.535	0.213
1997	0.420	0.169
1998	0.381	0.136
1999	0.320	0.158
2000	0.290	0.156
2001	0.428	0.173
2002	0.306	0.091
2003	0.203	0.096
2004	0.163	0.099
2005	0.175	0.118

[a] Full-selection fishing mortality rates.
[b] Catch/biomass rate is the ratio of catch to beginning year age 3+ biomass.
[c] The 2005 catch/biomass rate is based on 2005 TAC

Table 15.14. Projections of female spawning (sp.) biomass in mt, full-selection fishing mortality rates (F) and catch in mt for Atka mackerel for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 239,700, 95,900, and 83,900 t, respectively.

Sp.Biomass (mt)	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2005	186,536	186,536	186,536	186,536	186,536	186,536	186,536
2006	141,122	155,850	156,794	152,307	174,305	134,670	141,122
2007	97,923	112,682	126,277	117,638	164,228	89,240	97,923
2008	82,663	89,532	112,010	101,864	161,529	75,346	80,243
2009	87,984	90,687	116,811	105,658	173,960	81,177	82,983
2010	94,770	95,803	125,490	113,146	189,944	87,242	87,836
2011	97,628	98,025	130,839	117,484	202,225	89,252	89,430
2012	99,132	99,292	134,427	120,331	211,975	90,238	90,291
2013	98,830	98,898	135,564	120,963	218,262	89,687	89,704
2014	98,988	99,018	136,527	121,648	223,176	89,818	89,825
2015	100,587	100,600	138,771	123,681	228,657	91,336	91,338
2016	101,726	101,732	140,650	125,344	233,402	92,255	92,256
2017	101,477	101,480	140,980	125,502	236,085	91,830	91,831
2018	100,750	100,751	140,466	124,903	237,262	91,110	91,110
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2005	0.204004	0.204004	0.204004	0.204004	0.204004	0.204004	0.204004
2006	0.435868	0.230396	0.217934	0.277909	0	0.533108	0.435868
2007	0.435868	0.435868	0.217934	0.277909	0	0.495407	0.435868
2008	0.37079	0.401034	0.217512	0.277909	0	0.412233	0.440455
2009	0.375589	0.384945	0.21154	0.277909	0	0.430221	0.43898
2010	0.389459	0.392155	0.211635	0.277909	0	0.453313	0.455748
2011	0.395973	0.396853	0.21283	0.277909	0	0.461801	0.462468
2012	0.397911	0.39826	0.21358	0.277909	0	0.461941	0.46214
2013	0.39865	0.3988	0.213669	0.277909	0	0.462914	0.462977
2014	0.399773	0.399837	0.214133	0.277909	0	0.462847	0.462871
2015	0.399203	0.399233	0.214365	0.277909	0	0.462654	0.462664
2016	0.400728	0.400739	0.214812	0.277909	0	0.466079	0.466083
2017	0.401559	0.401564	0.214712	0.277909	0	0.467735	0.467737
2018	0.399904	0.399907	0.214535	0.277909	0	0.463837	0.463837
Catch (mt)	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2005	63,000	63,000	63,000	63,000	63,000	63,000	63,000
2006	110,214	63,000	59,881	74,610	0	130,031	110,214
2007	78,468	90,954	49,864	59,466	0	81,509	78,468
2008	54,880	65,024	43,677	50,744	0	55,488	63,703
2009	56,428	59,947	42,171	49,682	0	59,778	62,602
2010	61,876	63,142	44,288	51,843	0	66,635	67,574
2011	65,128	65,599	46,610	54,076	0	69,802	70,090
2012	66,748	66,934	48,390	55,752	0	70,845	70,929
2013	67,023	67,101	49,183	56,430	0	70,897	70,923
2014	67,359	67,394	49,736	56,860	0	71,021	71,031
2015	68,172	68,187	50,442	57,629	0	72,080	72,085
2016	69,091	69,098	51,103	58,305	0	73,211	73,212
2017	69,194	69,198	51,312	58,499	0	73,244	73,245
2018	68,597	68,599	51,246	58,376	0	72,236	72,237

Table 15.15. Ecosystem effects

Ecosystem effects on Atka mackerel			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys	None	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on Atka mackerel	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	No concern
Fish (Pacific cod, arrowtooth flounder)	Pacific cod and arrowtooth abundance trends are stable	None	No concern
Changes in habitat quality			
Temperature regime	2002 AI summer bottom temperature 2nd coldest year after 2000 survey	Colder than average year, could possibly affect fish distribution	Unknown

***The Atka mackerel* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Likely to be a minor contribution to mortality	Unknown
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	Unknown
HAPC biota (seapens/whips, corals, sponges, anemones)	Low bycatch levels of seapens/whips, sponge and coral catches are variable	Unknown	Possible concern for sponges and corals
Marine mammals and birds	Very minor direct-take	Likely to be very minor contribution to mortality	No concern
Sensitive non-target species	Skate catches are variable and have averaged 66 mt from 2000-2004, which is about 28% of the AI skate catch over this time period	Data limited, need species-specific catch information	Possible concern
Other non-target species	Sculpin catch is variable, large increases in bycatch in 2002 & 2004	Unknown	Unknown
Fishery concentration in space and time	Steller sea lion protection measures spread out Atka mackerel catches in time and space	Mixed potential impact (fur seals vs Steller sea lions)	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Probably no concern
Fishery contribution to discards and offal production	Offal production—unknown The Atka mackerel fishery contributes an average of 56 and 76% of the total AI trawl non-target and target discards, respectively.	The Atka mackerel fishery is one of the few trawl fisheries operating in the AI. Numbers and rates should be interpreted in this context.	Unknown
Fishery effects on age-at-maturity and fecundity	Unknown	Unknown	Unknown

15.16 Figures

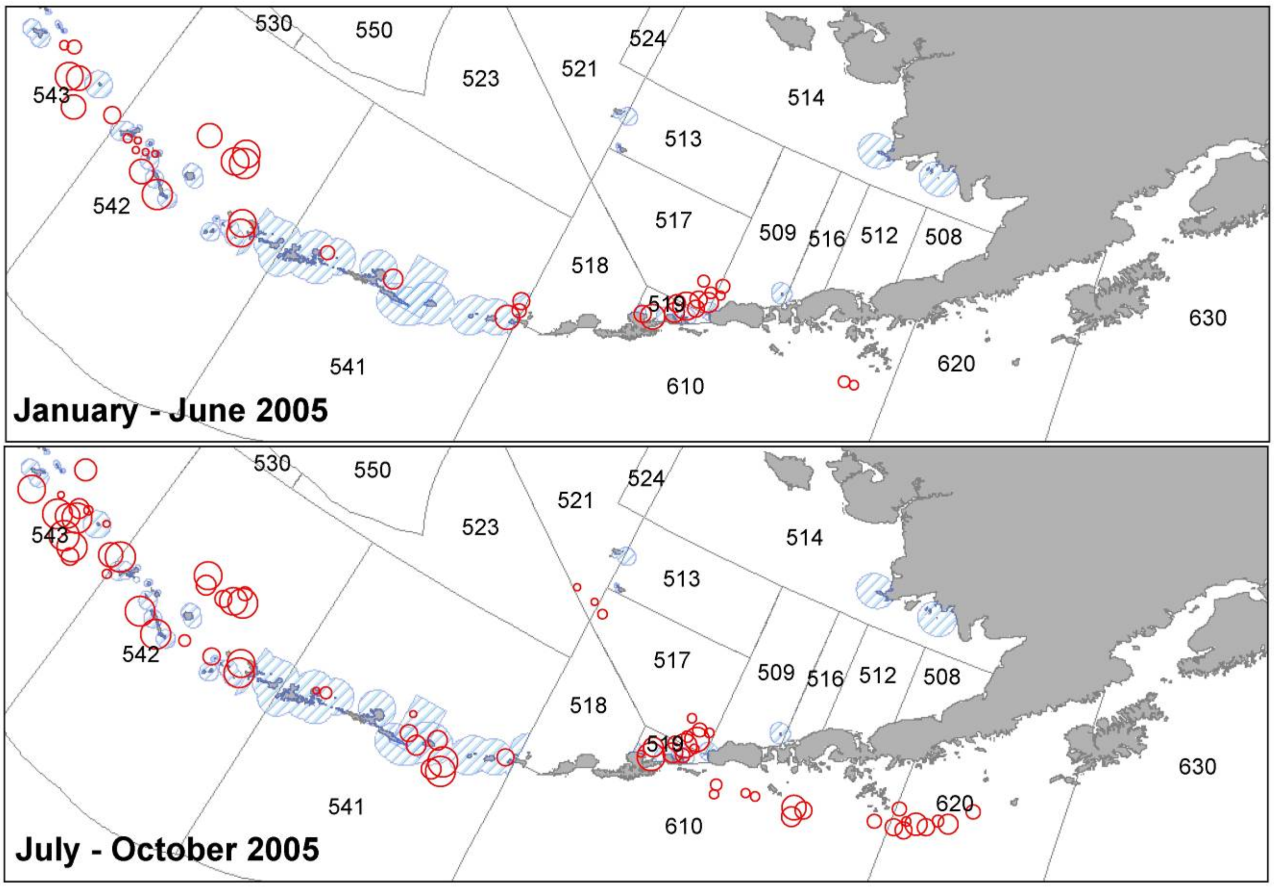


Figure 15.1. Observed catches of Atka mackerel summed for 20 km^2 cells for 2004 (January – June, top panel; and from July-October, bottom panel) where observed catch per haul was greater than 1mt. Shaded areas represent 10 and 20 nm Steller sea lion areas.

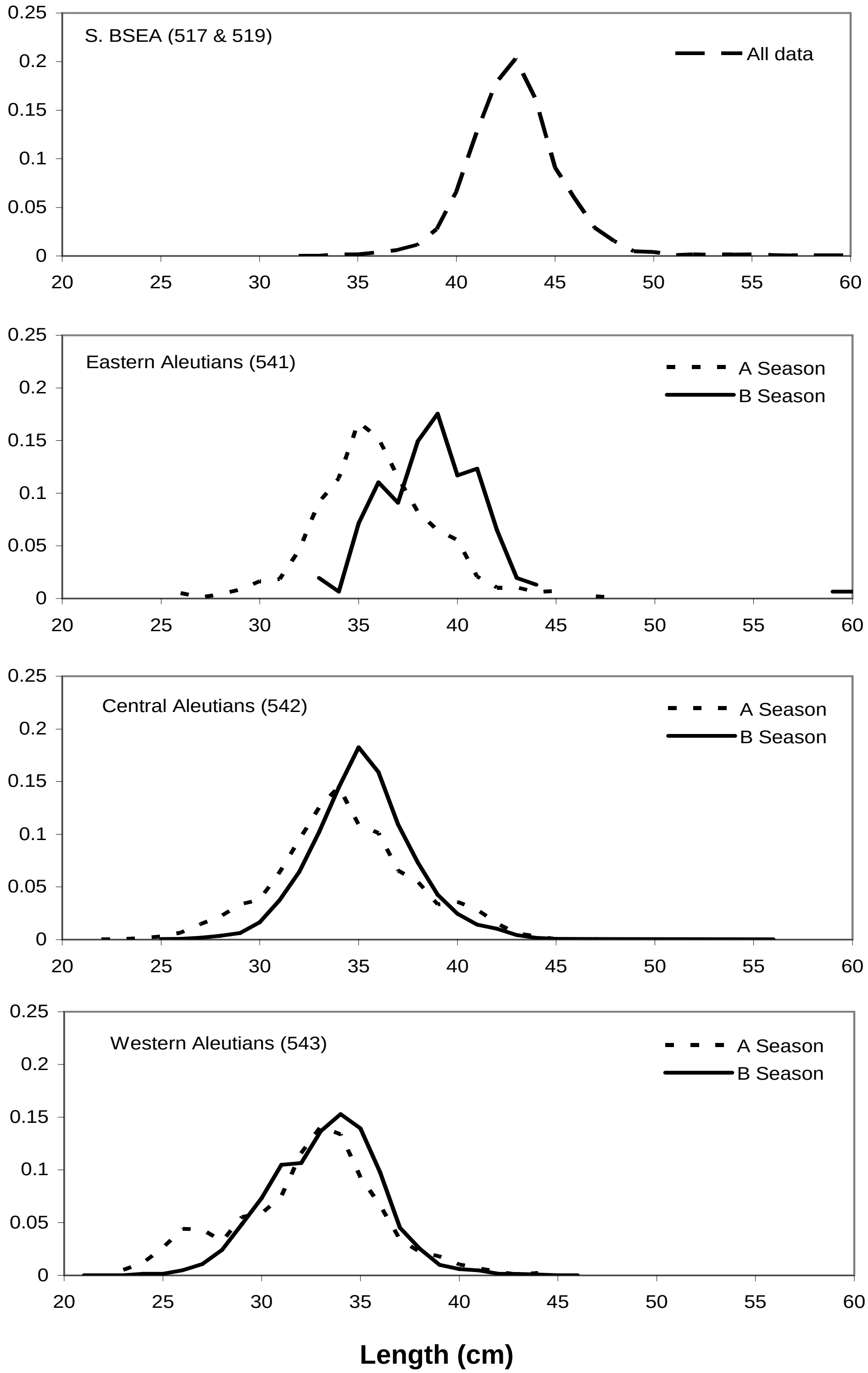


Figure 15.2. 2004 Atka mackerel fishery length-frequency data by area fished (see Figure 15.1). Numbers refer to management areas.

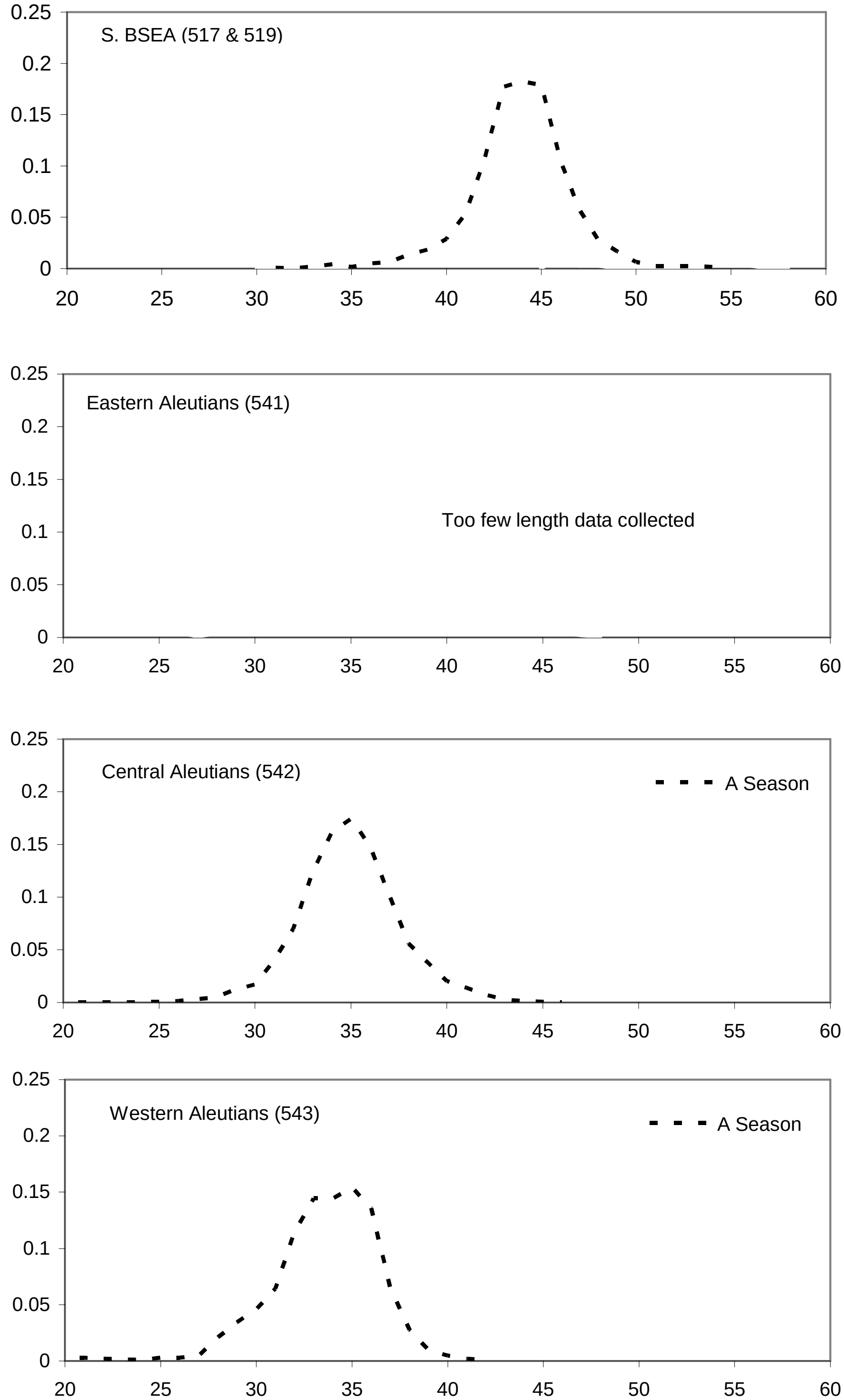


Figure 15.3. Preliminary 2005 A-season Atka mackerel fishery length-frequency data by area fished (see Figure 15.1). Numbers refer to management areas.

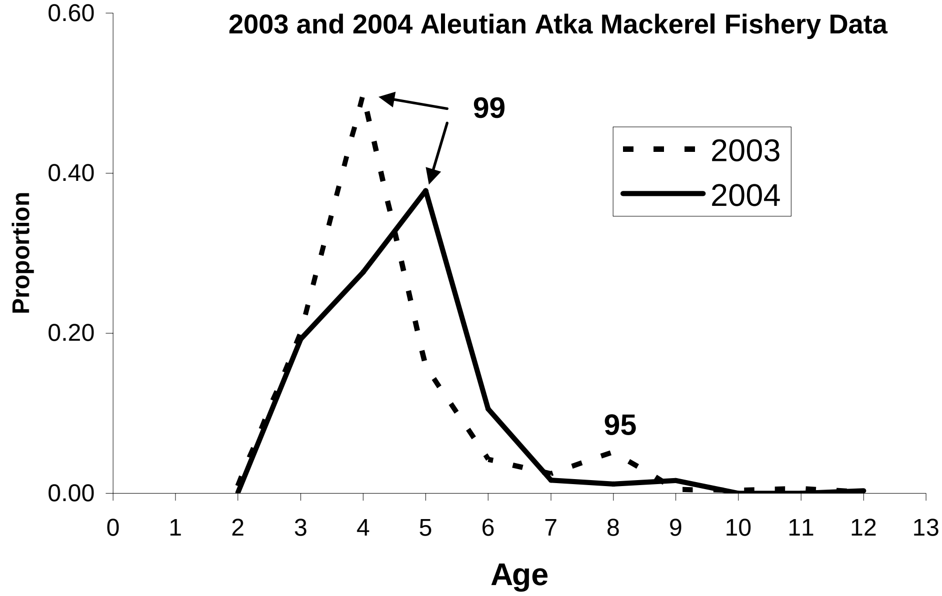


Figure 15.4. 2003 and 2004 Aleutian Atka mackerel fishery age composition data.

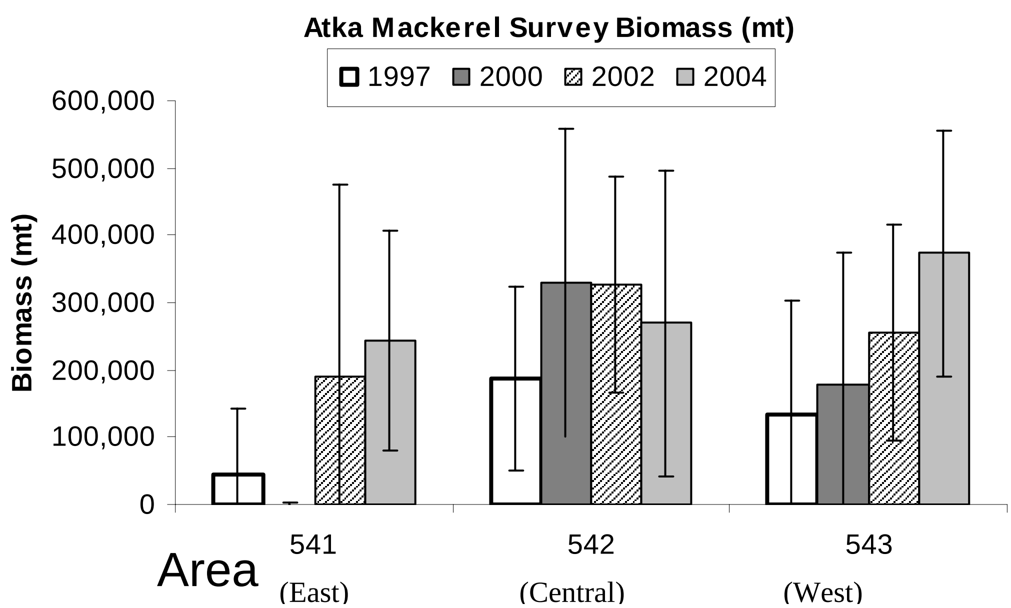


Figure 15.5. Atka mackerel Aleutian survey biomass estimates by area and survey year. Bars represent 95% confidence intervals based on sampling error.

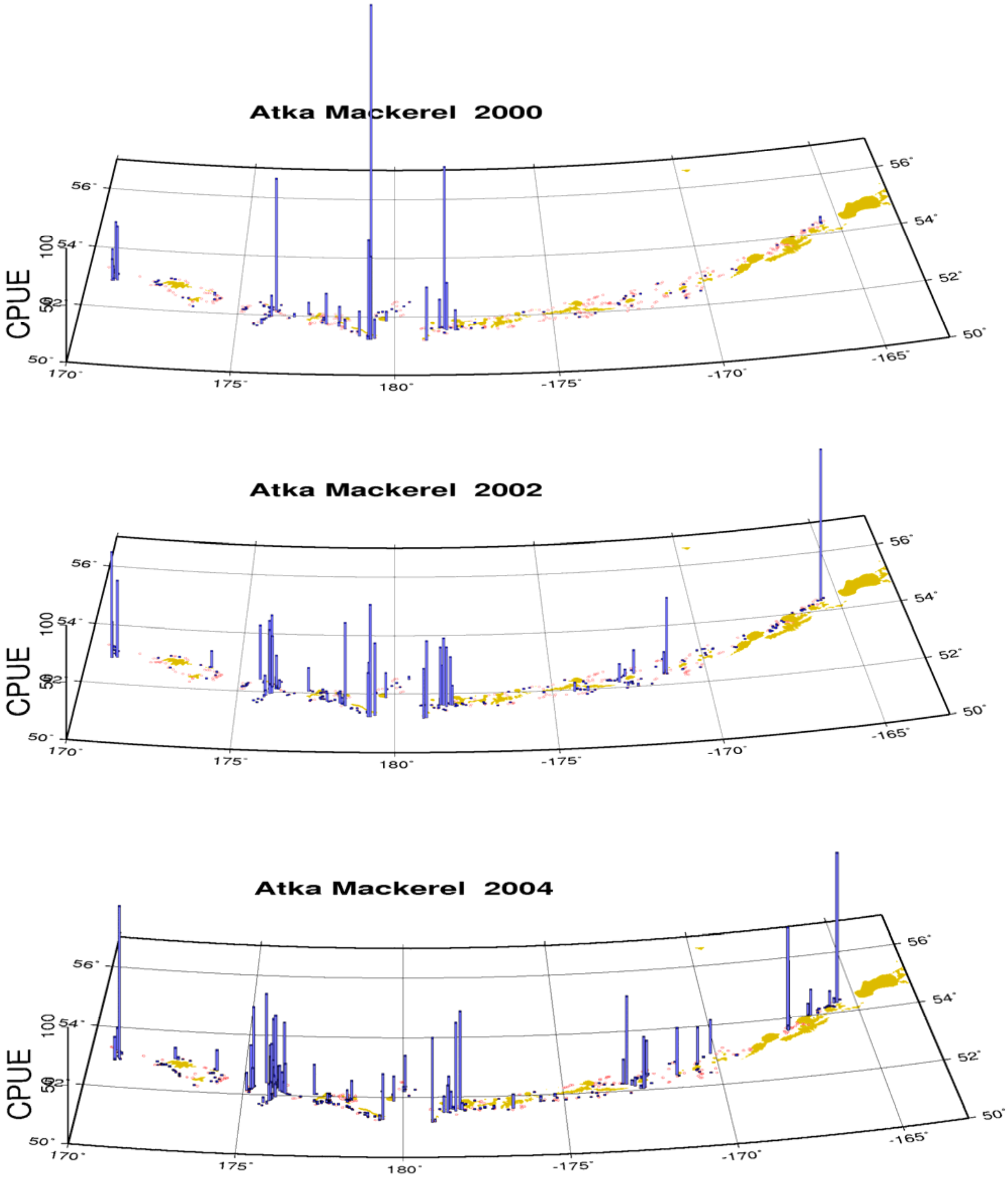


Figure 15.6. Bottom-trawl survey CPUE distributions of Atka mackerel catches during the summers of 2000, 2002, and 2004.

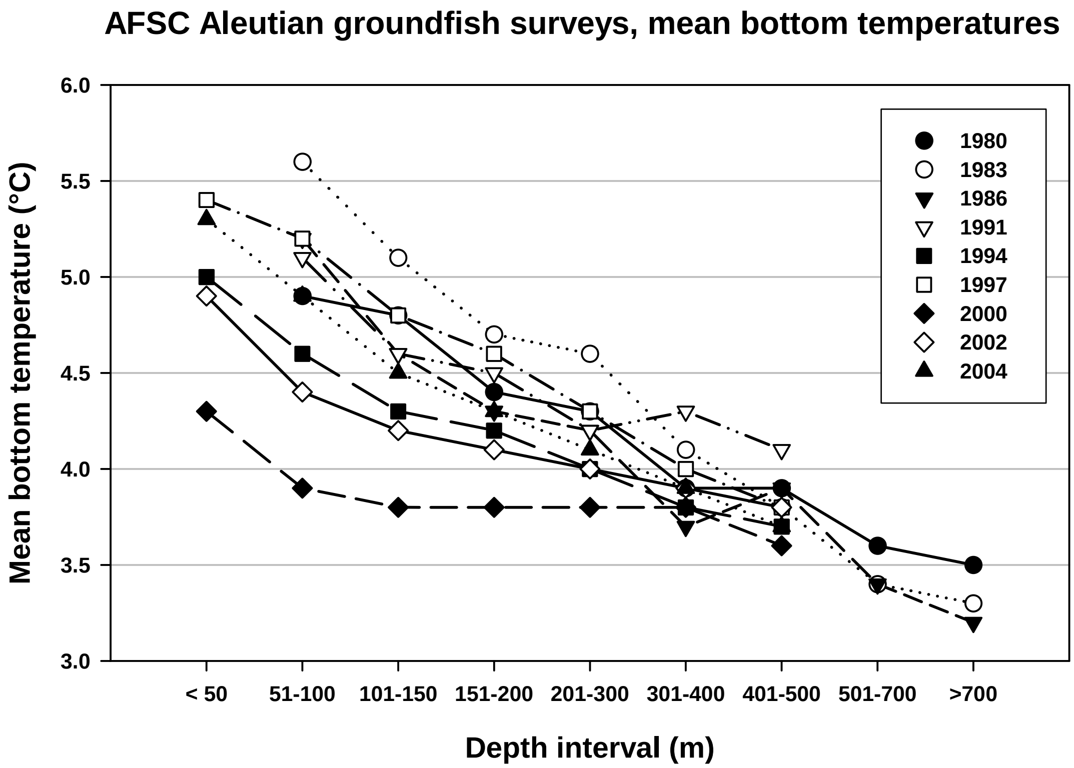


Figure 15.7. Average bottom temperatures by depth interval based on Aleutian Islands summer bottom-trawl surveys since 1980.

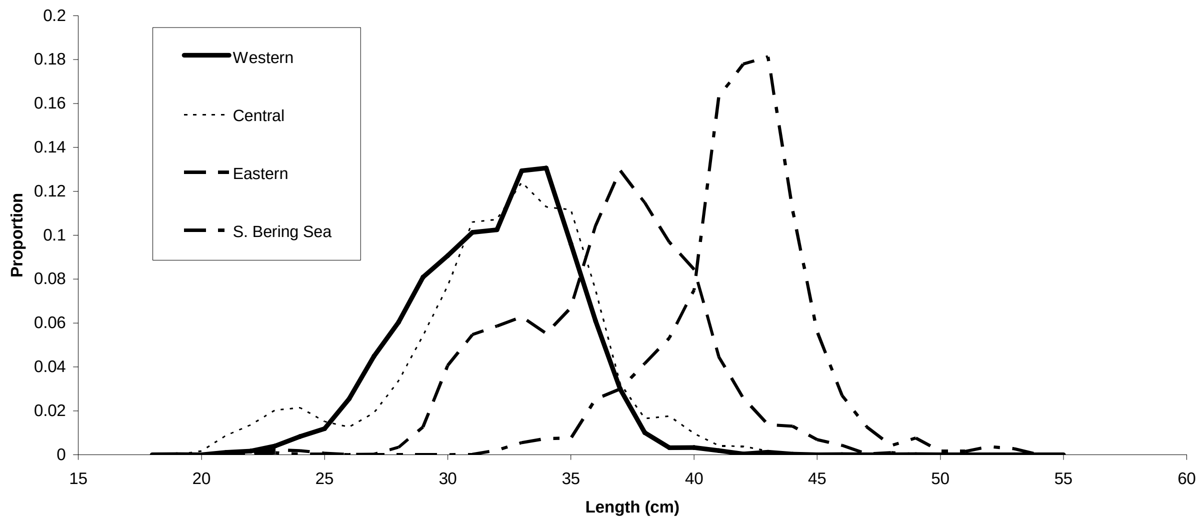


Figure 15.8. Atka mackerel bottom trawl survey length frequency data by subarea from the 2004 Aleutian Island survey.

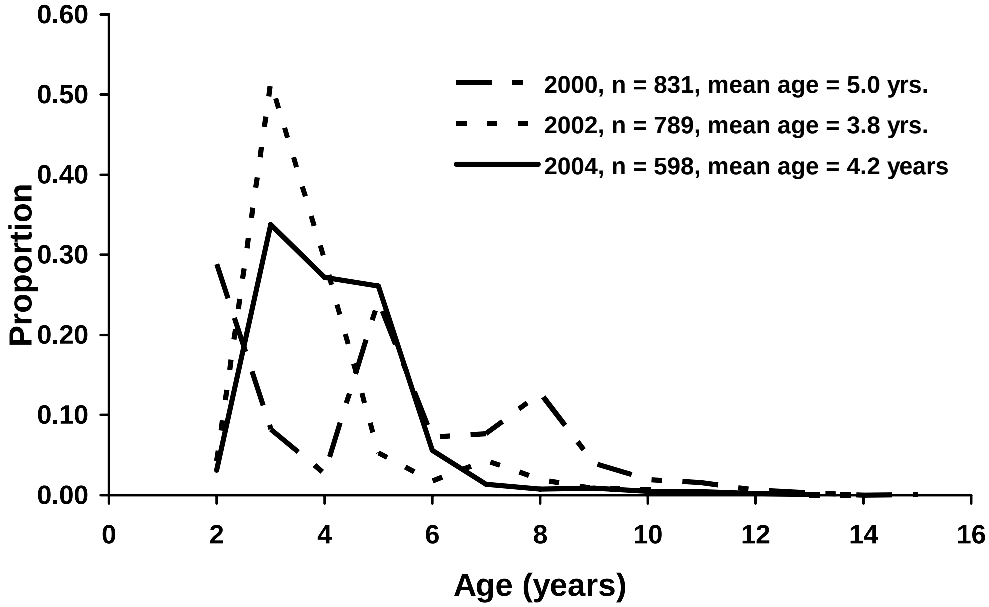


Figure 15.9. Atka mackerel age distributions from the Aleutian Islands region from the 2000, 2002, and 2004 bottom trawl surveys.

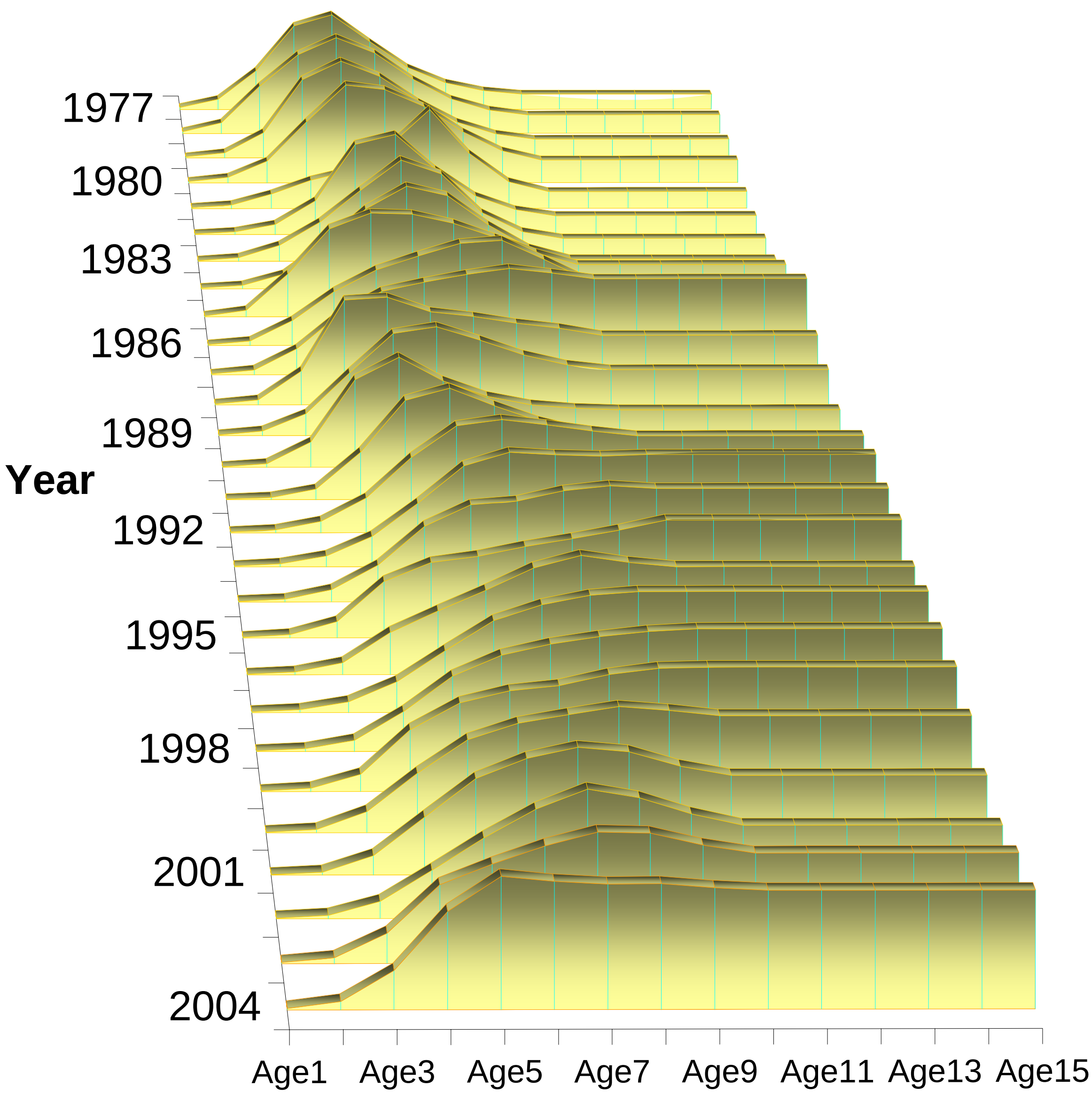


Figure 15.10. Estimated annual Atka mackerel fishery selectivity-at-age patterns.

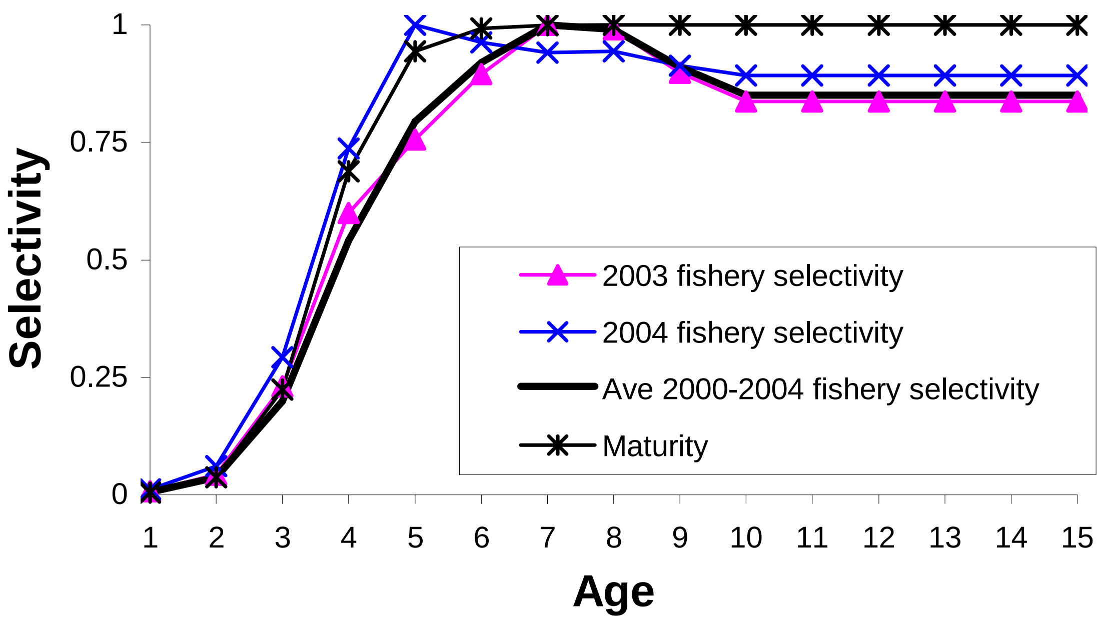


Figure 15.11. Estimated 2003, 2004, and the average of the 2000-2004 selectivity-at-age patterns compared with the maturity at age estimates for Atka mackerel.

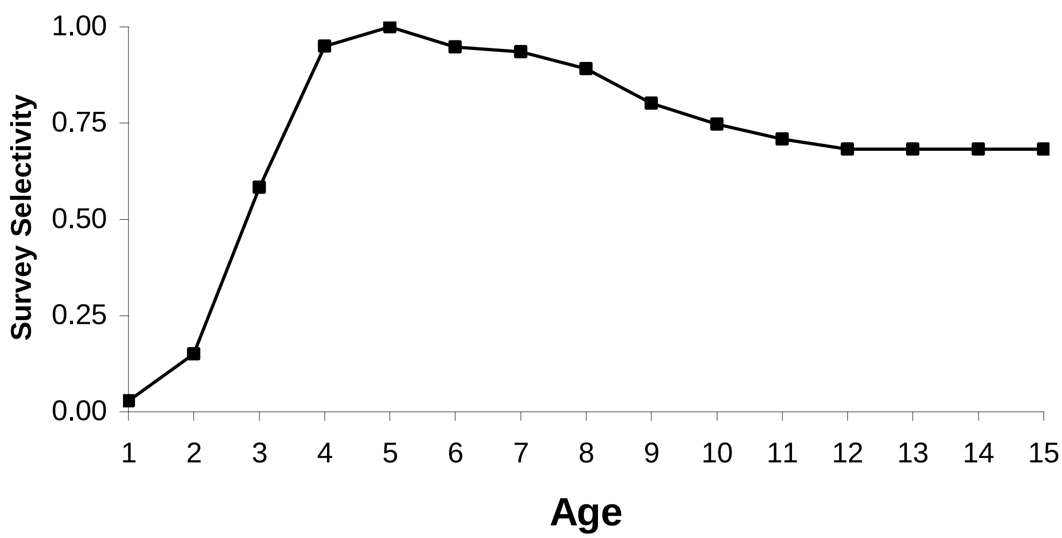


Figure 15.12. Estimated Atka mackerel survey selectivity-at-age.

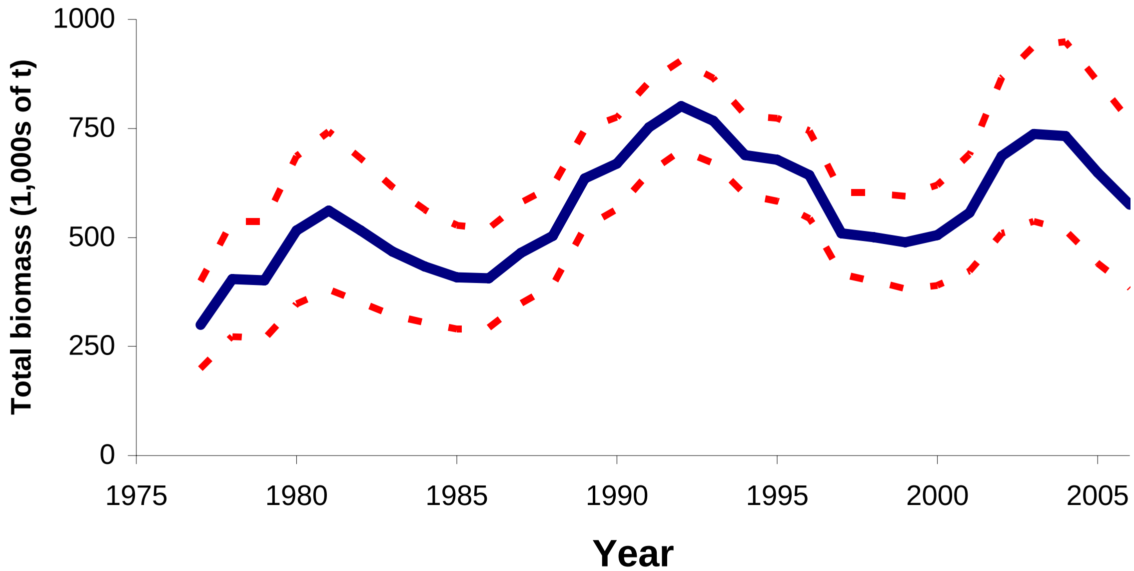


Figure 15.13. Time series of Atka mackerel total (age 1+) biomass estimates and approximate 95% confidence bounds.

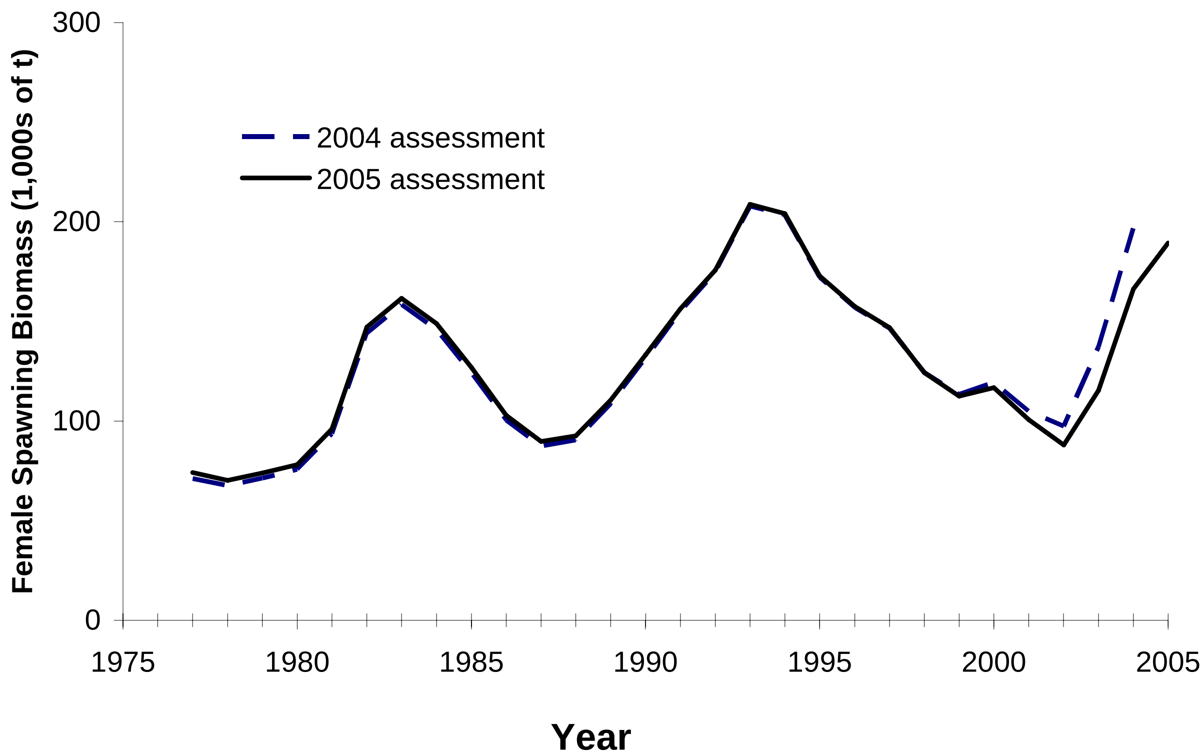


Figure 15.14. Comparison of Lowe et al.'s (2004) assessment of BSAI Atka mackerel to the current estimate of female spawning biomass.

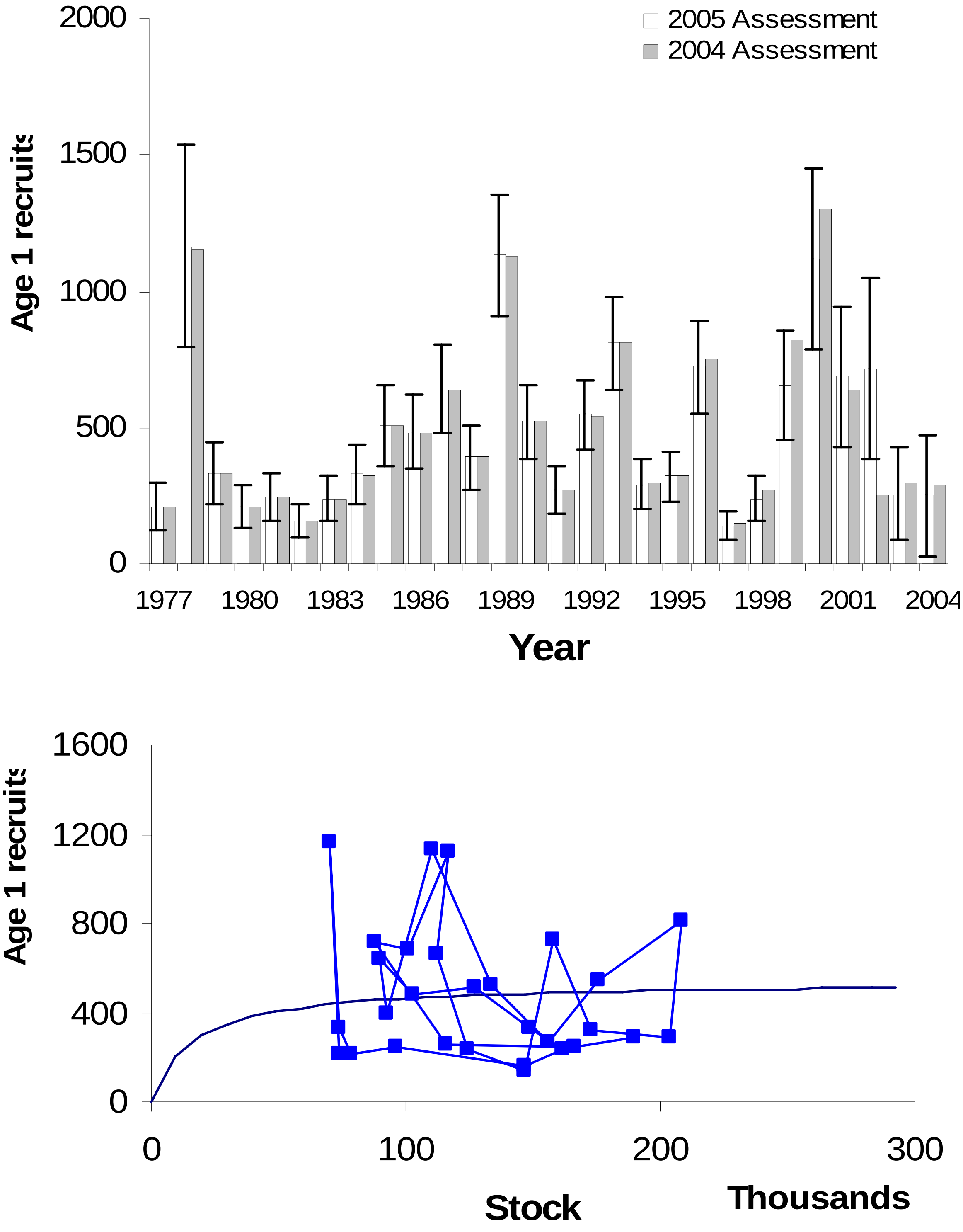


Figure 15.15. Age 1 recruitment of Atka mackerel as estimated from the current assessment, with error bars representing two standard errors (top panel) and estimated female spawning biomass levels (lower panel). Solid line represents the underlying Beverton-Holt stock recruitment curve assumed in the model.

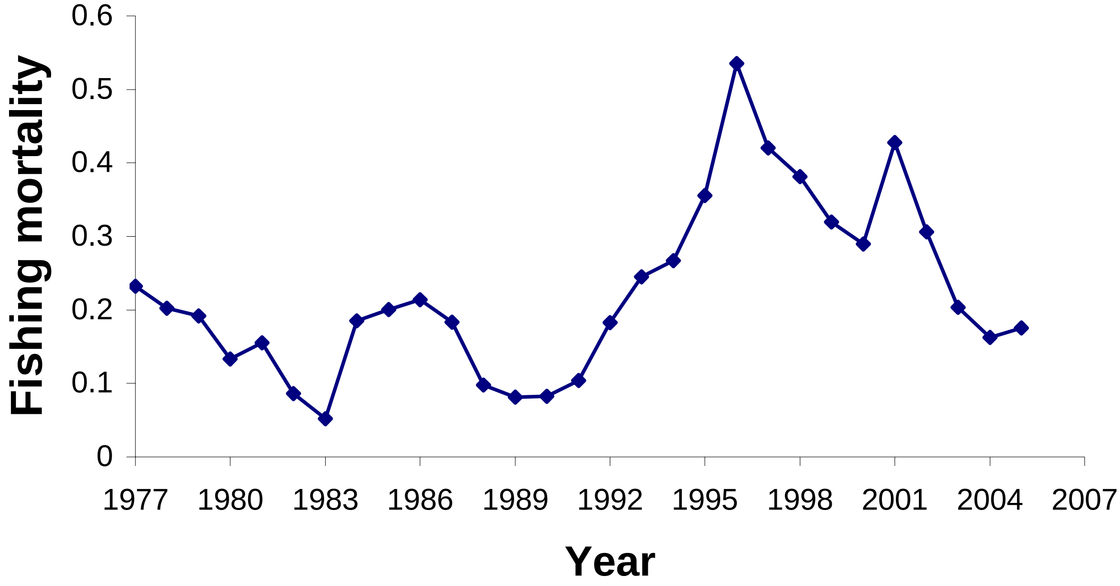


Figure 15.16. Estimated time series of full-selection fishing mortality rates of Atka mackerel, 1977-2005.

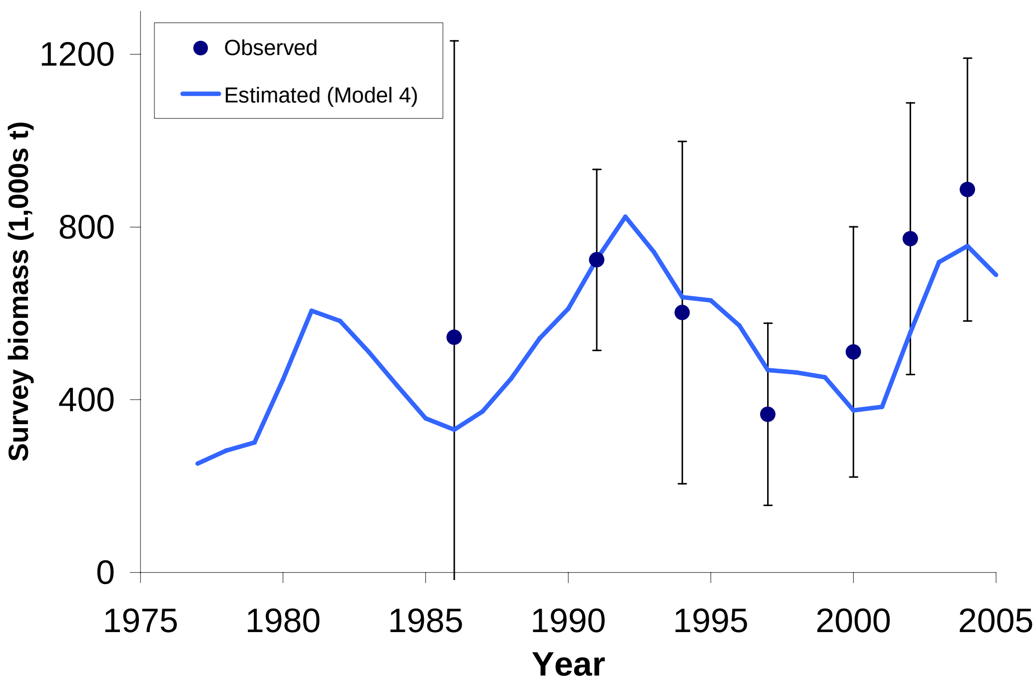


Figure 15.17. Observed and predicted survey biomass estimates for Aleutian Islands Atka mackerel. Error bars represent two standard errors (based on sampling) from the survey estimates.

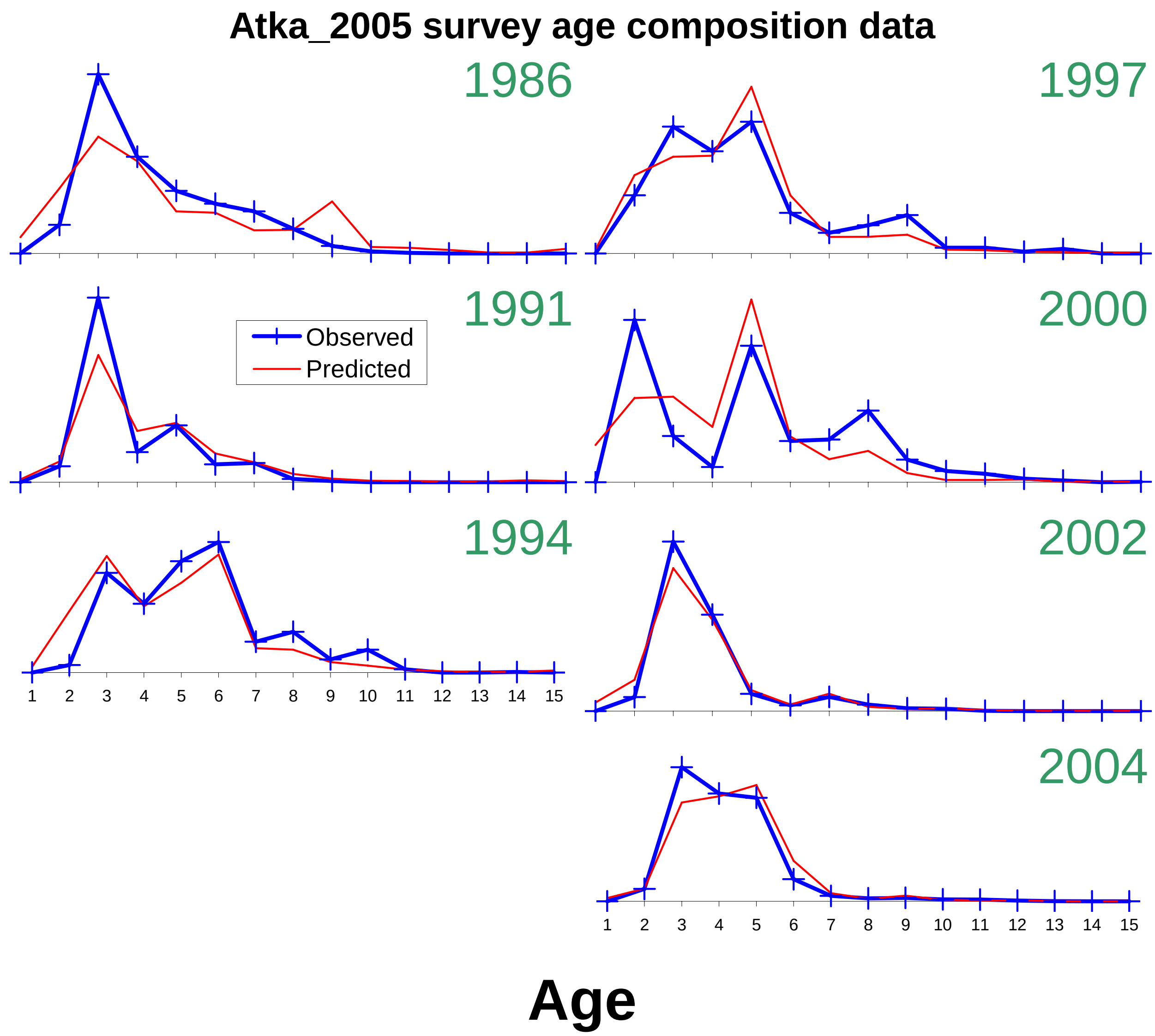


Figure 15.18. Observed and predicted proportions-at-age for Atka mackerel. Continuous lines are the model predictions and lines with "+" symbol are the observed proportions at age.

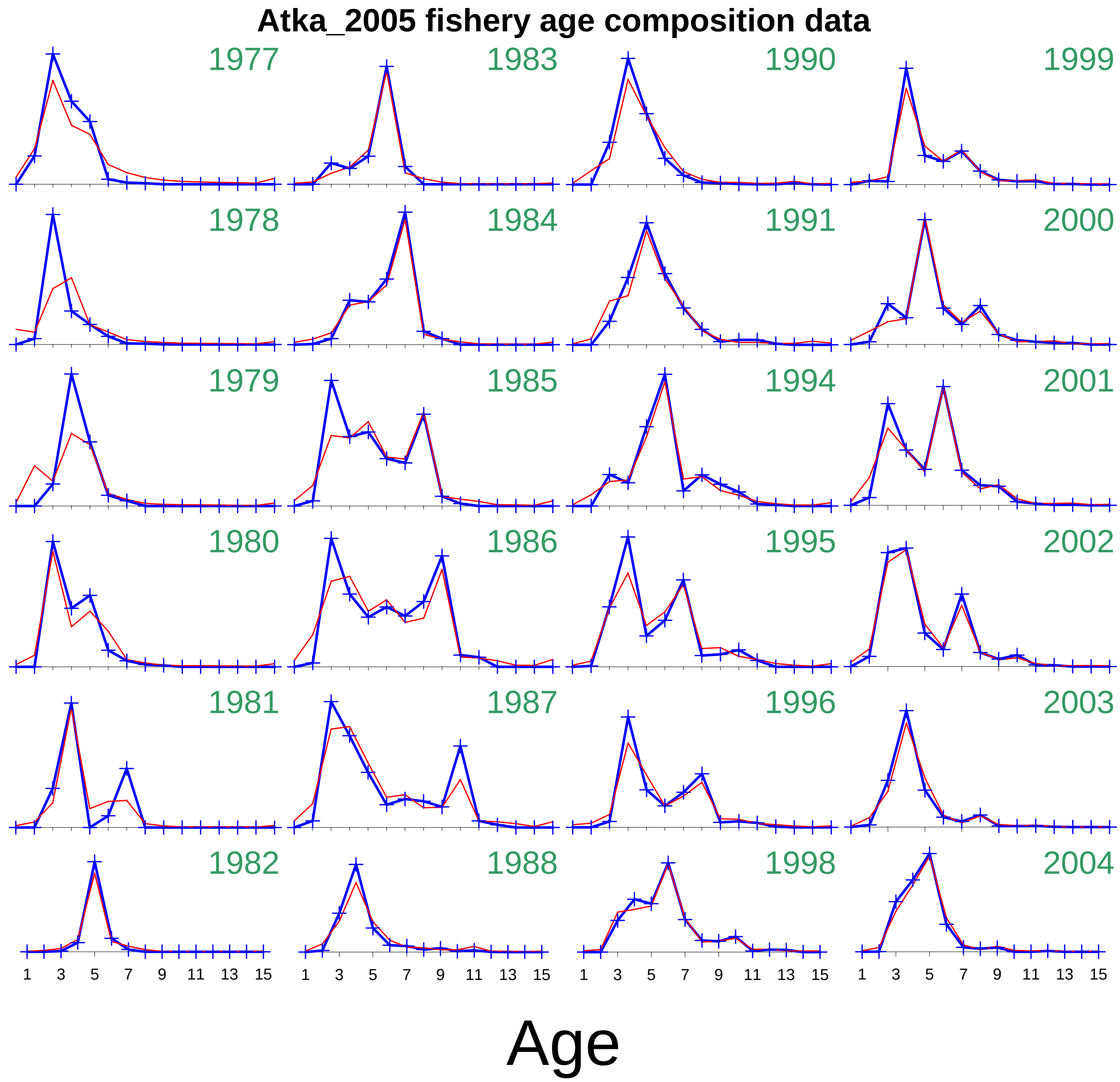
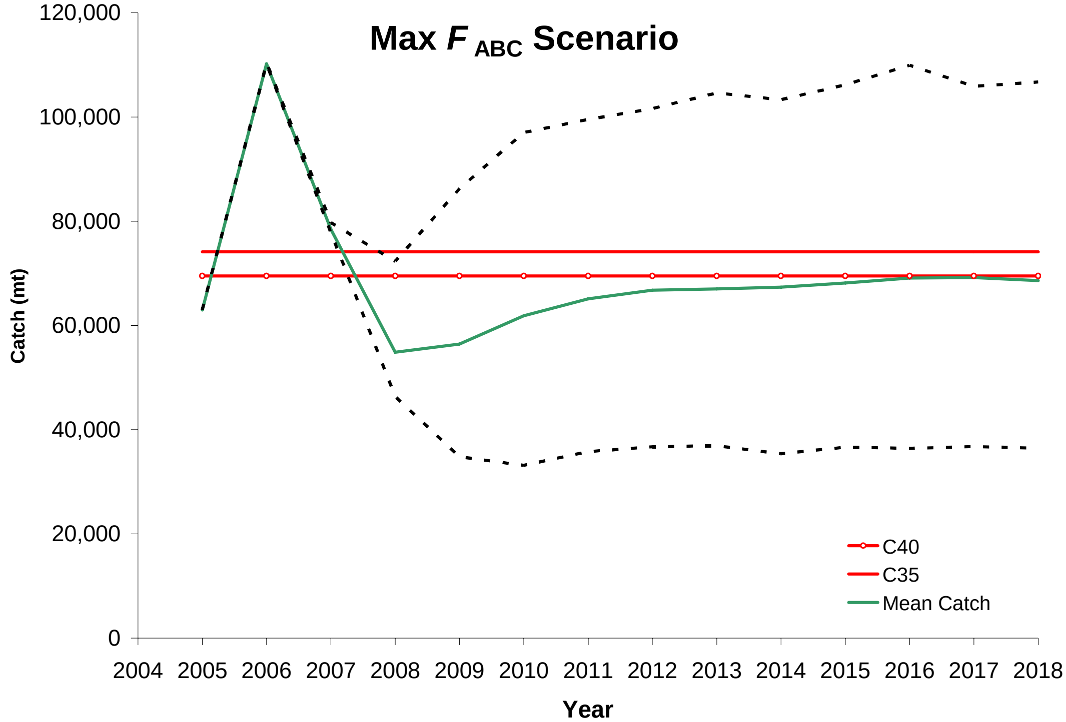


Figure 15.19. Observed and predicted Atka mackerel proportions-at-age for fishery data. Continuous lines are the model predictions and lines with "+" symbol are the observed proportions at age.



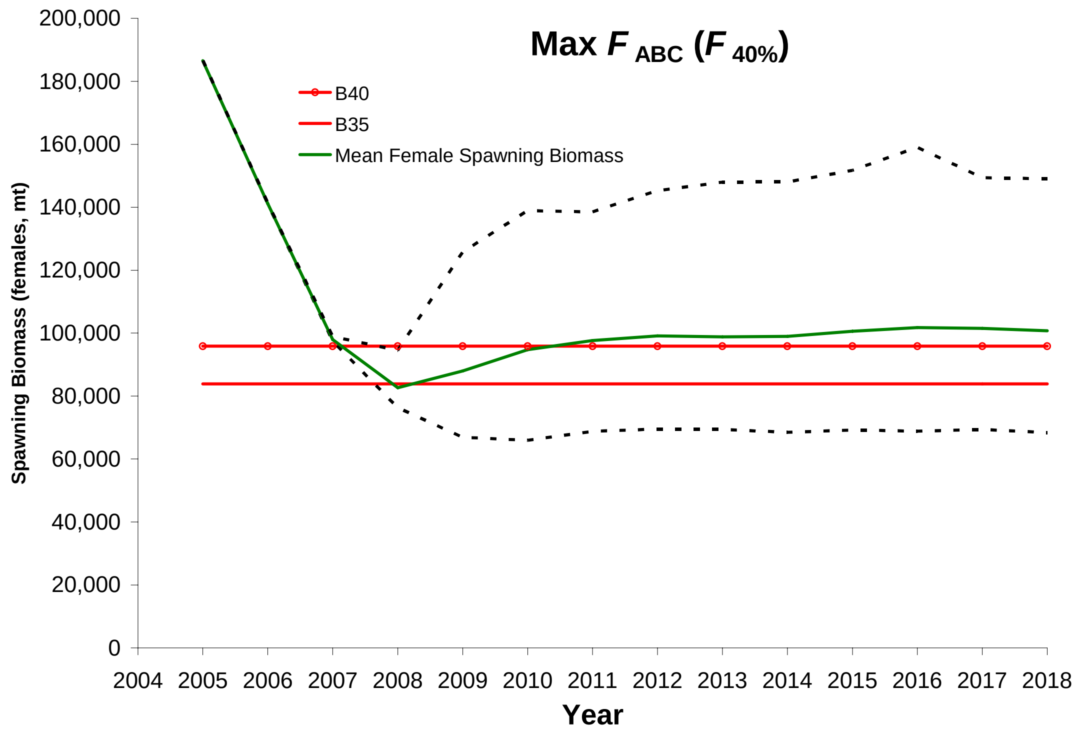


Figure 15.20. Projected catch in mt (top) and spawning biomass in mt (bottom) under maximum permissible Tier 3a harvest levels.

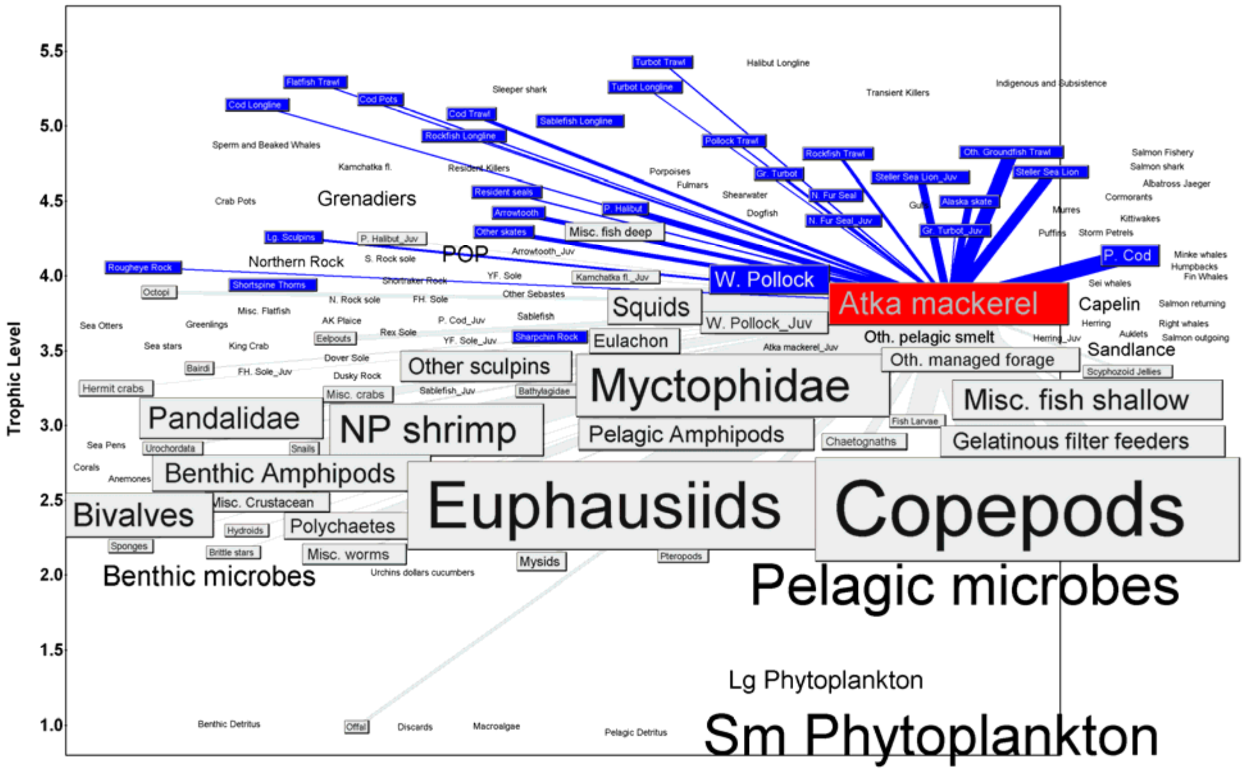
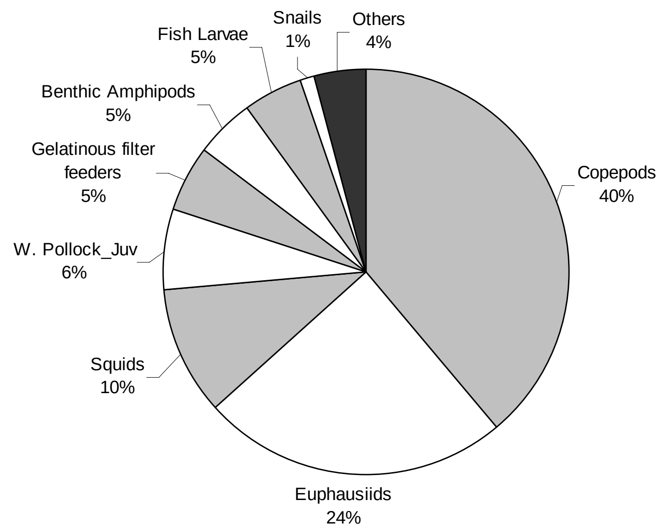


Figure 15.21. The food web of the Aleutian Islands survey region, 1990-1994, emphasizing the position of age 1+ Atka mackerel. Outlined species represent predators of Atka mackerel (dark boxed with light text) and prey of Atka mackerel (light boxes with dark text). Box and text size are proportional to each species' standing stock biomass, while line widths are proportional to the consumption between boxes (mt/year). Trophic levels of individual species may be staggered up to +/-0.5 of a trophic level for visibility.

(A)



(B)

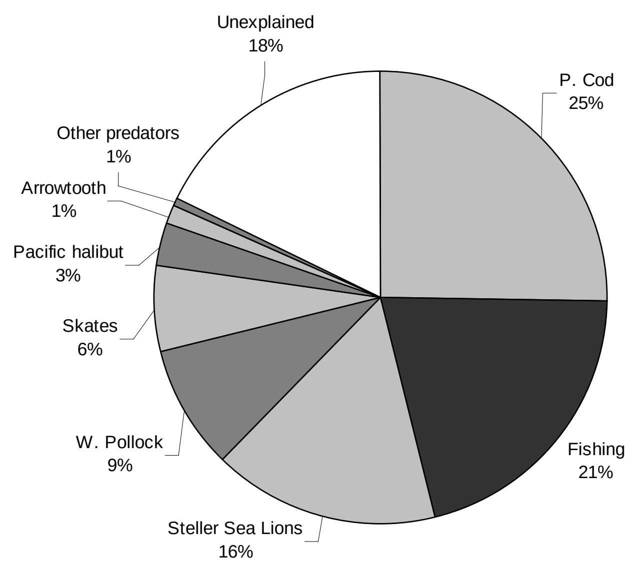


Figure 15.22. (A) Diet of age 1+ Atka mackerel, 1990-1994, by percentage wet weight in diet weighted by age-specific consumption rates. (B) Percentage mortality of Atka mackerel by mortality source, 1990-1994. "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

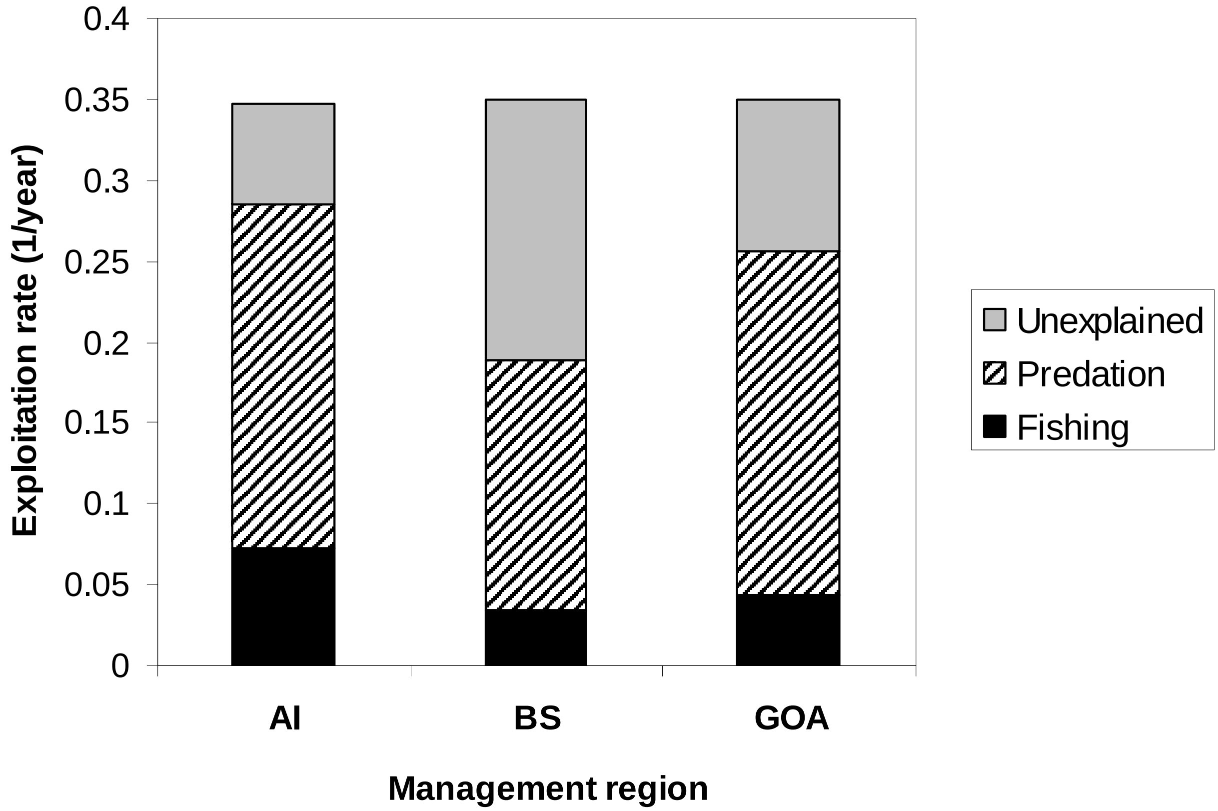


Figure 15.23. Total exploitation rate of age 1+ Atka mackerel, 1990-1994, proportioned into exploitation by fishing (black), predation (striped) and "unexplained" mortality (grey). "Unexplained" mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment using predator diets, consumption rates, and fisheries catch.

Appendix 15.A

Table A-1. Variable descriptions and model specification.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1977, …., 2004}		i
Age index: j = {1, 2, 3, …, 14, 15^+}	j	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Fixed M=0.30, constant over all ages
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion at age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(1.0 , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Stock-recruitment variance
Estimated parameters		
$\phi_i(26),\ R_0,\ h,\ \varepsilon_i(41), \sigma_R^2,\ \mu^f,\ \mu^s,\ M,\ \eta_j^s(14),\ \eta_j^f c(14), F_{50\%}, F_{40\%}, F_{30\%}, q^s$		

Note that the number of selectivity parameters estimated depends on the model configuration.

Table A-2. Variables and equations describing implementation of the Assessment Model for Alaska (AMAK).

Description	Symbol/Constraints	Key Equation(s)
Survey abundance index (s) by year	Y_i^s	$\hat{Y}_i^s = q_i^s \sum_{j=1}^{15^+} s_j^s W_{ij} e^{Z_{i,j}\frac{7}{12}} N_{ij}$
Catch biomass by year	C_i	$\hat{C}_i = \sum_j W_{ij} N_{ij} \frac{F_{ij}}{Z_{ij}} \left(1 - e^{-Z_{ij}}\right)$
Proportion at age j, in year i	$P_{ij}, \ \sum_{j=1}^{15} P_{ij} = 1.0$	$P_{ij} = \frac{N_{ij} s_{ij}^f}{\sum_{k=1}^{15} N_{ik} s_{ik}^f}$
Initial numbers at age	$j = 1$	$N_{1977,1} = e^{\mu_R + \varepsilon_{1977}}$
	$1 < j < 15$	$N_{1977,j} = e^{\mu_R + \varepsilon_{1978-j}} \prod_{j=1}^{j} e^{-M}$
	$j = 15^+$	$N_{1977,15} = N_{1977,14} \left(1 - e^{-M}\right)^{-1}$
Subsequent years ($i > 1977$)	$j = 1$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
	$1 < j < 15$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = 15^+$	$N_{i,15^+} = N_{i-1,14} e^{-Z_{i-1,14}} + N_{i-1,15} e^{-Z_{i-1,15}}$
Year effect, i = 1963, …, 2004	$\varepsilon_i, \ \sum_{i=1963}^{2004} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
Index catchability Mean effect	μ^s, μ^f	$q_i^s = e^{\mu^s}$
Age effect	$\eta_j^s, \ \sum_{j=1}^{15^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$ $\quad j \le$ maxage $s_j^s = e^{\eta_{\text{maxage}}^s}$ $\quad j >$ maxage
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$
mean fishing effect	μ_f	
annual effect of fishing in year i	$\phi_i, \ \sum_{i=1977}^{2001} \phi_i = 0$	
age effect of fishing (regularized) In year time variation allowed	$\eta_{ij}^f, \ \sum_{j=1}^{15^+} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $\quad j \le$ maxage $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $\quad j >$ maxage
In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne$ change year
Natural Mortality	M	
Total mortality		$Z_{ij} = F_{ij} + M$
Recruitment Beverton-Holt form	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = \tilde{R}_0 \varphi$ $\varphi = \frac{e^{-15M} W_{15} p_{15}}{1 - e^{-M}} + \sum_{j=1}^{15} e^{-M(j-1)} W_j p_j$

Table A-3. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

Likelihood /penalty component		Description / notes
Abundance indices	$L_1 = \lambda_1 \sum_i \ln\left(Y_i^s \big/ \hat{Y}_i^s\right)^2 \frac{1}{2\sigma_i^2}$	Survey abundance
Prior on smoothness for selectivities	$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{15^+} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l\right)^2$	Smoothness (second differencing), Note: l={s, or f} for survey and fishery selectivity
Prior on recruitment regularity	$L_3 = \lambda_3 \sum_{i=1963}^{2004} \varepsilon_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_4 = \lambda_4 \sum_{i=1977}^{2001} \ln\left(C_i / \hat{C}_i\right)^2$	Fit to survey
Proportion at age likelihood	$L_5 = -\sum_{l,i,j} T_{ij}^l P_{ij}^l \ln\left(\hat{P}_{ij}^l \cdot P_{ij}^l\right)$	l={s, f} for survey and fishery age composition observations
Fishing mortality regularity	$L_6 = \lambda_6 \sum_{i=1977}^{2004} \phi_i^2$	(relaxed in final phases of estimation)
Priors	$L_7 = \left[\lambda_7 \frac{\ln\left(M/\hat{M}\right)^2}{2\sigma_M^2} + \lambda_8 \frac{\ln\left(q/\hat{q}\right)^2}{2\sigma_q^2}\right]$	Prior on natural mortality, and survey catchability (reference case assumption that these are precisely known at 0.3 and 1.0, respectively).
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{7} L_i$	

(This page intentionally left blank)